The European Commission JRC-IPTS and Enterprise DG

The impact of EU regulation on innovation of European Industry

Regulation and innovation in the area of end-of-life vehicles

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The views expressed in this study do not necessarily reflect those of the European Commission (EC).
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## INTRODUCTION

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## PART I.

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**Frequently used abbreviations**

- **ASR**: automobile shredding residue
- **ELV**: end-of-life vehicle (also denotes sector/area)
- **DFD**: design for dismantling
- **DFR**: design for recycling
- **FTB**: free take-back
- **LCA**: life-cycle analysis
- **RRR**: recovery/reuse/recycling (targets)
- **VA**: voluntary agreement
The close of the last millennium saw unprecedented mergers and acquisition activity in the automotive industry. The automotive industry is currently re-shaping its strategies to answer to the new challenges of global competition.

One of the key objectives for the automotive industry is now to gain an in-depth understanding of the environmental and social concerns of all the different stakeholders involved. To achieve this, industry needs to set up an efficient monitoring system to track developments especially changes in demands of consumers and the emergence of new legislation. The draft EU Directive proposal on the end-of-life vehicles (ELV) as so far created a lot of turmoil amongst car manufactures both in terms of potential increased costs of production and waste management and on the creation of new business opportunities.

The Institute for Prospective Technological Studies (IPTS) of the European Commission Joint Research Centre (JRC) has embarked in a major work exploring the link between regulation and innovation of European industries.

This report represents the results of intensive two years work by the IDSE-CNR and we believe that its analysis will shed some lights on the complex and manifold relationship between legislation, at European and national level, and the innovation behaviour of car manufactures.

Some of its preliminary conclusions have been already discussed in open and specialised forum and many have been the feedback and suggestions that have been taken into account during the carrying out of the study. We would like in particular to thank DG Enterprise, DG Environment and DG Research for their valuable inputs.

This report will serve IPTS in its main task of feeding into the reflections of the European policy makers. In particular we hope that the information enclosed will help to better understand the complex and sometimes ambiguous relationship between regulatory issues, instruments and actions and the innovation behaviour of a multifaceted and rapidly evolving ELV chain.

F.Leone/L.Delgado
INTRODUCTION

The mission of IDSE-CNR was to study the relationships between regulation and innovation in the area of end-of-life vehicles (ELV). The required impact analysis included the following aspects of regulation-innovation relationships: (a) the regulation process; (b) initiatives by car manufacturers; (c) links between policy instruments and innovation in ELV; (d) innovation in the car industry; (e) policy performance and recommendations.

A preliminary study on regulation and innovation in ELV carried out by IDSE-CNR (see Zoboli 1998) revealed: (i) a systemic profile of the ELV problem in the perspective of regulation-innovation relationships; (ii) strong limitations of the available information base for the research mission. As a consequence, the basic choices of the research study have been: (a) a methodological approach addressing ELV regulation-innovation as a systemic problem, also based on methodological suggestions from the IPTS-JRC project as a whole; (b) a research approach based on direct contacts and interviews with the economic and institutional actors of the ELV system in Europe.

A series of 35 direct interviews and other contacts at the European Commission (DG ENTR, DGXI, and DG RTD), professional associations involved in the ELV problem, and carmakers’ recycling departments were organised. The list of the interviews is enclosed at the end of the Report. Some other requests for direct interviews did not receive positive reply. Other direct contacts were possible during the international conference on “Car recycling in Europe” (Munich, March 10th-11th, 1999). In general, the coverage of interviews and contacts can be considered as largely representative, albeit not exhaustive, of the ELV actors in Europe. Interviews and direct contacts supplied a rich set of information and documents (sometimes having a limited circulation).

Most of the interviews took place when the EU Directive proposal on ELV of 1997 passed through the First Reading by European Parliament (February 1999) until the Council Common Position (July 1999). Every care has been taken to avoid that this Report was influenced by the positions in the debate about the Directive, as expressed by interviewed representatives of professional association, carmakers, and European policy-makers at the Commission.

The presentation of the research results is structured in two volumes.

Volume 1 ("Research Report") fulfils the main requirements of the research mission. It is structured in three main parts.

- Part I addresses the ELV problem and policy developments at the European level by depicting: (a) the ELV system and its present state from the environmental, technological, and economic point of view; (b) the policy/regulation initiatives in Member States and the

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1 Technical Annex of IPTS-JRC call for tender for studies on "The Impact of EU Regulation on Innovation of the European Industry" (92/50/EEC - 98/S 75-44736) and contract for the study "Regulation and Innovation in the Area of End-of-Life Vehicles" (No. 14401-1998-10 FIED SEV IT)
regulation-making process at the EU level. The analysis is open by a short overview of structural changes of the automobile technological system in Europe.

- Part II addresses in details the ongoing initiatives for ELV in single EU15 countries as well as Norway, the United States, and Japan, and focuses the developments taking place in major European car companies as emerging from direct interviews and documents².

- Part III analyses the innovation process and the role of regulation as emerging from Part I and Part II. It addresses in particular the set of specific innovations underway, the systemic features of the innovation process, the existence of different innovation paths, the relationships between regulators and innovators, the role of specific policy instruments. The cost-benefit implications of regulation on ELV are then outlined.

- Main results and policy recommendations are presented at the beginning of the Research Report.

Volume II ("Technical Analyses") supplies a deeper and more technical examination of innovations in ELV and car recycling/recyclability. The “technical analyses”, that maintain a focus on environmental and economic aspects, can add important elements for understanding the innovative developments that the Research Report puts in the regulation-innovation perspective. Volume II is structured by topics including design for the environment, ELV disposal technologies, automobile material evolution, automobile plastic recycling, as well as other specific aspects of car recycling.

Volume II will be published at a later stage and due to its ‘heaviness’ both in terms of number of pages and graphical content will be only available in electronic format.

The Report is based on the information available at December 15, 1999 and some updated information arising in January-February 2000, e.g. the early results of Parliament’s second reading of ELV Directive.

² A detailed analysis of the Swedish case was added to the five detailed country analyses (France, Germany, Italy, the Netherlands, and the United Kingdom) originally included in the IDSE-CNR project.
Acknowledgements

The research work has been carried out at IDSE-CNR (the Research Institute on the Dynamic of Economic Systems of National Research Council of Italy) by: Roberto Zoboli (IDSE-CNR, Project Leader); Giancarlo Barbiroli (University of Bologna); Nicola De Liso (IDSE-CNR); Riccardo Leoncini (IDSE-CNR); Massimiliano Mazzanti (University of Rome III and IDSE-CNR); Sandro Montresor (University of Bologna and IDSE-CNR).

The authors of the Report’s parts are:


The interviews have been carried out by R. Leoncini, M. Mazzanti, and R. Zoboli.

Analyses presented in the Report have been discussed, in their preliminary version, during the workshops organised by IPTS-JRC for the “Regulation-Innovation” project. In particular, we thank Gerhard Becher, Diana Bredford, Jens Hemmelskamp, Celia Graves, René Kemp, Fabio Leone, Gérald Petit, Keith Smith, Horst Steg and the other participants to the workshops for their comments and useful suggestions. The continuous stimulus and help by Fabio Leone and Jens Hemmelskamp (IPTS-JRC) during the research work is gratefully acknowledged.

The research work greatly benefited from the cooperative exchange of information with Oliver Schulte of Org-Consult (Mainz, Germany). In particular, we gratefully acknowledge the possibility to mutually integrate and crosscheck the information on ELV in European countries arising from the “parallel” IDSE-CNR and Org-Consult research works.

We gratefully acknowledge people we have interviewed during the research work (see “List of Interviews”), and we especially thank people supplying us detailed and written information and/or open discussions on the ELV issue.

The Report also benefited from the comments to papers on the ELV case-study presented by R. Zoboli at the following conferences and workshop: International Conference on “Innovation-Oriented Environmental Regulation”, IPTS-JRC, ZEW, MERIT, Potsdam, May 27th-29th, 1999; “Recycling Forum” (Working Group C, Research and Innovation), European Commission - DG ENTR, meeting of November 9th, 1999, Brussels; Workshop on “Ecological Product Policy: Potential Role of the Stakeholders”, European Environmental Bureau, Brussels, December 10th, 1999. Comments received in various instances on the IDSE-CNR preliminary study on ELV (Zoboli 1998) are also acknowledged.

All responsibilities have to be assigned only to the producers of the Report.

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Executive Summary

According to official estimates, around nine million end-of-life vehicles (ELVs — passenger cars) arise every year in the EU. They are recycled (metals) for an estimated 75% of total weight, while the remaining 25%, i.e. the shredding residue containing various mixed materials including hazardous substances, is landfilled for the most part. ELVs abandoned in the environment, pollution arising from dismantling if not performed in appropriate ways, and landfiling of shredding residue are the main environmental externalities of ELV.

Starting from the European Commission’s ‘Community strategy for waste management’ (1989), a process of regulation-making at the EU level for ELV went on during the 1990s. The Commission produced an EU directive proposal (1997), including quantitative targets for ELV recovery/reuse/recycling (RRR), materials’ limitations, technical prescriptions on treatment, and economic instruments. After a very difficult debate between regulators and industry, the Council arrived at the common position of July 1999. After the second reading by Parliament in February 2000, the ELV directive is going to be adopted during 2000, whereas the car industry is still opposing some of its main provisions.

In parallel to EU regulation-making, most Member States implemented different forms of voluntary agreements for ELV management and/or national regulations that include the car industry and the other industries operating in ELV and car-making.

As a consequence of the expected directive and voluntary agreements based on industrial initiatives, a wide set of technological and organisational innovations took place in the ELV-related industries during the 1990s. Specific innovation ranges from the creation of ELV treatment infrastructures to design for dismantling and design for recycling. Innovation in ELV, however, has complex systemic features requiring interrelated changes to be undertaken by different industries operating in both car design and downstream ELV recovery operations. The features of the innovation process can be influenced by specific regulation choices.

The state of the ELV problem, regulation, and industrial initiatives

The state of ELV in the European Union

Most of the material flows, environmental externalities, and techno-economic relationships of the ELV chain are still poorly measured or not precisely defined in most Member States and the EU as a whole.

The estimates on the number of ELVs to be treated in Member States are highly uncertain. The figure adopted in the EU directive proposal, i.e. eight to nine million ELVs in 1994, is questioned because of the great number of ELVs deregistered in EU countries and exported mostly to non-
EU countries for treatment or reuse as second-hand cars. The actual number of ELVs treated
domestically in EU countries could have been 7.5 million units in 1998, i.e. 20 to 30 % less than
the official figure. There are no reliable figures on the number of ELVs that are abandoned.
ELVs can have an economic value to last owners ranging from positive to negative according to
various factors. When delivery to a dismantler implies a payment, this can be an incentive to
abandon the car.

The rates of ELV recycling/recovery/reuse in the EU are still rough estimates. The overall rate
of recovery/reuse/recycling is generally estimated at 75 % of the car weight that corresponds to
the metal (ferrous and non-ferrous) content recovered in the dismantling and shredding phases.
The automobile shredding residue (ASR) is assumed to correspond to the remaining 25 % of the
car weight. ASR is generally landfilled and represents a major externality addressed by ELV
policies and industrial experiences. The estimated amount of ASR (2.2 million tonnes) represents
less than 1% of the total waste generated in the EU, but the Commission estimates that it
represents 10 % of the total hazardous waste generated in the EU. Classifications of ASR are
still uncertain. A procedure for including it in the European ‘Hazardous waste’ list is under way.
The composition of ASR can be very variable according to the treatment of ELVs in the
dismantling and shredding phases. The presence of substances such as polychlorinated biphenyl
(PCB) makes the environmental impact of ASR a critical issue despite the not too large
quantities. The presence of plastics’ residues contributes to the relatively high calorific value of
ASR-derived fuel and makes the energy recovery option attractive at the industrial level.

Significant changes in the car material regime occurred during the last few decades and the
material composition of new cars produced in the late 1980s and early 1990s (i.e. ELVs of the
next decade) shifted further towards polymeric materials and aluminium. Compared with their
extensive role in car-making, many plastics are significantly difficult to recycle from ELVs.
Aluminium is the main metal having an increasing share in car material mix and the automotive
sector is the main market for recycled aluminium.

Parts and materials from ELVs give rise to recovery/reusing/recycling chains that have different
degrees of actual development, innovation opportunities, and constraints. Car production is an
important market for some recovered/reusable/recycled materials.

The recovery of spare parts is the main business of collectors/dismantlers. Although the car
spare parts market in Europe is undergoing interesting developments, it is still less developed
than the US market. Ferrous and non-ferrous metals recovered by shredding are the other most
important materials’ stream from ELVs and, at the same time, ELVs represent an important
source of raw materials for the secondary metal industry. The amount of plastic waste from
ELVs was estimated at 796 000 tonnes in 1997. Only 8.3 % is mechanically recycled while
around 15 % is recovered an as energy source (as a part of ASR). The most part (76.6 %) is
currently landfilled as a component of ASR. Because of economic constraints, the potential for
automotive plastic waste recycling in Europe is estimated at no more than 10 % by 2006. The
demand for recycled plastics in new car production is estimated at 4 % for the same year. Tyres
from ELVs represent 10 % of the total annual used-tires in the EU. They are usually removed
from ELVs before shredding but not always at 100 % rates. ELV batteries are usually treated
to recycle lead. There are no figures on the possible extent of non-removal of batteries and the
impact of their harmful components on ASR composition. Non-appropriate fluid removal and
dispersion in the environment can cause contamination of dismantling sites, while non-removal of fluids implies their transmission to the shredding phase and then to landfilled ASR. The information on fluids actually removed from ELVs in the EU is highly incomplete in both quantitative and qualitative terms.

**Developments of EU regulation**

ELV was identified as a ‘priority waste stream’ by the Commission’s ‘Community strategy for waste management’ (1989). After a long process of problem identification and solution definition, the EU regulation-making process arrived at the ELV directive proposal in 1997. The directive proposal addressed ELV as a waste-management problem to be faced on the basis of financial ‘extended producer responsibility’ and it involved product-making to a large extent. The directive proposal included: quantified targets on recovery/reuse/recycling of ELVs; technical/environmental standards for dismantling and treatment operations; limitations on some heavy metals in car materials and components; limitations on ASR energy recovery; a free take-back obligation by car-makers; and the future direct regulation of car recyclability. It implicitly excluded voluntary agreements.

Industries opposed most of the provisions as they were formulated, and, in particular, free take-back, the timing of targets as applied to cars already on the market (‘retroactivity’), the limitations on ASR energy recovery, and the limitations on heavy metals in alloys. The preference for industry was for ‘shared responsibility’ and industrial voluntary agreements. Only dismantlers were favourable to free take-back because of induced incremental costs of ELV treatment. Only technical regulations on dismantling and treatment were a ground of consensus between industry and EU policy-makers.

The extensive debate and the very controversial process of adoption went on during 1998 and 1999. A great number of amendments were proposed in the Parliament’s first reading (February 1999). In July 1999, the Council reached a ‘common position’ that changes some important points of the original 1997 directive proposal. The approval by Parliament at the second reading (February 2000) left some key points of the directive unclear.

The main provisions of the 1999 common position are: (a) collection/dismantling facilities must be authorised; last owners will receive a certificate of destruction; treatment facilities must fulfil requirements specified in Annex I; many components must be removed; (b) by 1 January 2006, the recovery/reuse rate of all ELVs will have to achieve 85 % in terms of weight and recycling/reuse 80 %; by 1 January 2015, the reuse/recovery rate of all ELVs will have to be 95 % of the weight and reuse/recycling 85 %; energy recovery is allowed up to 5 % of weight by 2005 and up to 10 % of weight by 2015; (c) amendments on car type-approval regulation will be prepared to ensure that vehicles will be reusable/recyclable to a minimum of 85 % and reusable/recoverable to a minimum of 95 % of weight; (d) Annex II specifies a list of limit values for lead, chromium and mercury to be used in materials and components; (e) car producers should meet all or a significant part of the cost of implementation and/or take back end-of-life vehicles without any cost for the last owner (free take-back); (f) Member States may transpose key provisions by means of agreements between the national authorities and
industries; agreements shall be enforceable and, in case of non-compliance, Member States must implement the directive by legislation.

National policies and voluntary agreements

At end-1999, 10 EU member countries (Austria, Belgium, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden and the United Kingdom) had specific regulations and/or industrial voluntary agreements (VAs) for ELV. Another three countries were discussing industrial agreements (Finland and Ireland) or introducing legislation (Denmark). Six countries (Austria, Belgium, Germany, Italy, the Netherlands and Sweden) combine VAs with legislation directly addressing ELV. Austria, France, Italy and the Netherlands introduced VAs or countywide initiatives before the drafting of the EU directive proposal. The VAs and legislation in other countries (Belgium, Germany, Portugal, Spain and Sweden) were developed in 1997–99 during the debate on the EU directive proposal.

A process of integration between industrial agreements and legislation occurred in Germany and Sweden after a long confrontation between industry and environmental policy-makers. In other large countries (France, Italy and the United Kingdom), ELV policy is mainly based only on VAs promoted by the car industry and involving a number of other industries. One major feature of these VAs is the absence of specific economic instruments of the FTB type and the prominence of free-market relationships. The agreement implemented in the Netherlands represents a specific approach for both its organisational framework and its economic incentives. A recycling fee is levied on new car prices and redistributed to dismantlers and recyclers to pay incremental recycling costs. Specific mechanical recycling targets are established. Most national voluntary agreements and/or legislation established a recovery target rate of 85% of car weight by 2002 and a total recovery target rate of 95% by 2015. Most countries specify the targets only in terms of recovery rates (not recycling rates, as in the EU directive) thus allowing unconstrained energy recovery of ASR.

Industrial initiatives

Renault SA. Renault developed an approach to ELVs based on a system for ELV collection and spare parts recovery, the development of recycling and energy recovery, and the improvement of car recyclability. R & D efforts were made on plastic recycling. The number of dismantlers contracted by Renault in 1997 was 270. An average recovery/reuse/recycling rate of 82.9% in the Renault system is calculated.

PSA — Peugeot Citroen. The design of vehicles to be 90% recyclable from 2002 is addressed. A second direction is the recycling of end-of-life parts and developing the reuse of certain parts. In the area of design for recycling (DFR), the group’s approach is based on the reduction of the diversity of materials and the increased use of recycled materials in new cars.

Adam Opel AG. The ELV strategy includes ELV recovery and car design. The network of dismantlers included 234 companies in 1998. DFR manuals for internal use specify the technical solutions for improving recoverability and recyclability. Recyclability coefficients are calculated for internal use. Life-cycle analysis (LCA) of materials and components is performed.
BMW. The strategy on ELVs and car recycling includes a network of 90 associated dismantlers and DFR/DFD. The DFR/DFD approach of BMW includes ‘dismantling parts charts’ containing guidelines and recommendations for designers. Recycling coefficients have been developed based on indices of ‘suitability for recycling’ of the components and parts.

Daimler-Chrysler. DFD/DFR guidelines are for internal use. They also include references to the European guidelines being produced at end-1999 by EuCar. DFD/DFR aims to simplify the material regime by reducing the number of plastics. DFR requires a lot of interaction with component producers. LCA is used for evaluating material alternatives.

Ford Motor Company. Ford applies: (a) restrictions on hazardous substances; (b) DFR guidelines; (c) parts marking/material coding standards; (d) targets for recyclability of new models and the use of recycled materials. In Germany, Ford developed a network of 170 to 180 dismantlers. The DFR guidelines focus on fasteners, material selection, and component design. LCA is used for material and component selection.

Fiat. The FARE system of Fiat Auto is focused on dismantling, the reuse of recycled materials and ASR energy recovery. The principles are shared responsibility and free market. The system is based on agreements between Fiat and professional associations/companies. The network of associated dismantlers included 312 companies in 1998. The recovery rate is calculated at 82% of car weight. Recyclability coefficients are elaborated for internal use. LCA is applied to materials and components.

Volvo Car Corporation. DFD/DFR is addressed together with car recycling and ASR energy recovery. The technical reference is the ECRIS project. DFD/DFR is based on guidelines to be applied to the parts and components of new models. DFD and DFR are partly shifting the responsibility on recyclability to component and material suppliers. Volvo developed a network of dismantlers which currently includes 70 companies.

The innovation process and the role of regulation

Specific innovations

Different specific innovations were developed by industry during the 1990s as a consequence of regulation threats and voluntary industrial agreements. They included: (a) creation of recycling departments and competencies in car companies; (b) creation of dismantling and recovery/recycling networks; (c) advances in design for dismantling; (d) advances in design for recycling; (e) adoption of life-cycle analysis; (f) material regime simplification in car production; (g) material competition and substitution; (h) advances in automotive plastic recycling; (i) research on innovative ASR recovery technologies; (j) cooperative research initiatives at the industrial level.
Systemic innovation

Observable induced innovations require the involvement of different industries operating in both ELV treatment and car-making and demand common efforts and close cooperation. The systemic dimension of ELV innovation is made more significant by the requirements established by ELV policies and regulations through recovery/reuse/recycling targets.

The innovation process has the features of a knowledge process, characterised by gradual achievements, various degrees of uncertainty and learning from experience. Part of the process is company-specific, but another component is systemic and based on knowledge externalities inside and outside the industrial networks. Capabilities external to car companies, especially in downstream operations, are defined over local economic environments. The process is still open and can be influenced by regulation.

Innovation paths

Different sequences of interrelated specific innovations can be identified and grouped to define ELV 'innovation paths' for the achievement of targets and objectives. The choice of the most appropriate path(s) can be influenced by policies and cost–benefit distribution. The three general paths are: (a) the 'material market creation' path, in particular for plastics; (b) the 'energy market creation' path, in particular with energy recovery of ASR; (c) the 'radical substitution' path, in particular as a reduced propensity to introduce composite and advanced materials not technically/economically suitable for recycling.

EU policy-makers have implicitly a preference for 'material market creation' while they are adverse to 'energy market creation'. Car-makers have a preference for a combination of 'energy market' and 'material market' creation. Dismantlers, shredders, and material producers/recyclers have differentiated preferences for the three paths, and some of them might even benefit from 'radical substitution'.

Interactions between policy-makers and industry

Expectations about regulation strongly shape the whole innovation process in ELV. Innovation initiatives and achievements occurred before the most important regulations at EU and national level were introduced.

The target rates originate from industry-level discussions during the early 1990s when little experience in ELV management was available. They reflect technological expectations, policy views, and strategic propositions by industry. Regulators assumed these targets to be feasible and made them legally binding while introducing specific targets for mechanical recycling.

The strong involvement of product-making in ELV regulation did not bring innovative policy approaches, especially in terms of technological knowledge disclosure and use, and it was, instead, a reason for conflict between regulators and industry.
The role of policy instruments

Specific instruments can have incentive properties for the choice of innovation path(s) and may work as ‘selection devices’ by constraining some innovative options while providing incentives to pursue other innovation solutions. Other instruments in the policy package may reduce these incentive effects or may complement them.

The limitation on ASR energy recovery discourages innovative efforts on energy market creation while giving impulse to material market creation.

The incentive effect of direct regulation of depollution and incremental dismantling is incomplete for sustainable innovative solutions and requires a combination with other instruments.

The definition of standards on car recyclability creates specific uncertainties. Recyclability defined as a specific share of car weight can largely depend on material mix rather than recyclability of materials. The same rate of car recyclability can be obtained with different material mixes, design, and car conceptions. Innovation implications of standard definition could be the way current efforts on DFD/DFR are taken into consideration. The definition of recyclability could be location-specific. If reusability is defined as the existence of car models in which parts and components can be reused, the attainment of reusability is easier than both recyclability and recoverability.

The partial influence of economic instruments on the direction of innovation may depend on their cost–benefit implications for the different actors and, then, on the (expected) reactions by the latter.

The free take-back (FTB) of the 1997 EU directive proposal is a ‘free’ FTB mechanism in which dismantlers can establish the (negative) price for ELVs, and the last owner will be fully reimbursed by the car-maker. Last owners have an opportunity cost from ‘free’ FTB as far as the starting situation is one of positive ELV prices. A significant uncertainty is the distribution of the incentive effect along the downstream part of the ELV chain. If the transfers associated with FTB are not shared among all industries in downstream operations, the creation of new recovery/reuse/recycling markets could be difficult.

In a recycling fee/subsidy charged on car prices, car-makers do not pay for ELVs and the reasons for distribution conflicts can be eliminated. Car-makers, however, are opponents of the Dutch recycling fee scheme and some of them prefer a form of FTB, while refusing a ‘free’ FTB. This preference comes from the possibility that FTB is formulated as a ‘controlled FTB’. FTB control can increase with its integration in voluntary agreements.

Incentives from voluntary agreements

The significant incentive property of VAs is that they can put in a framework of inter-industry cooperation a set of actual/potential economic conflicts between the actors involved. Technical interdependency between ‘partial’ innovations inside innovation paths, in particular ‘material market creation’, creates the shared interest that all the actors can work in a proper way.

Although all the innovative developments on ELV have emerged inside VAs, many agreements have not yet achieved their own objectives. The variety of VAs and their incomplete deployment
in various countries prevent a definition of the form of agreement having the best incentives for innovation. Good performances seem to be related to a large industrial participation, investments in DFD/DFR by the car-makers, successful creation of dismantling networks, and sufficient experience allowing a deeper learning process.

Legally binding targets and legislation threats from the future directive may represent an incentive for VAs by creating a dividend of expected cost saving from VAs compared with direct regulation.

**Costs and benefits**

Explicit cost–benefit analyses (CBAs) of the EU directive and its provisions are not available. Cost–benefit analysis of environmental regulation is subject to conceptual and practical difficulties when responses to regulation consist of innovation processes. An important level of regulation’s CBA could be the cost-effectiveness of different policy approaches (provisions, instruments) and the associated cost–benefit (CB) distribution between industrial actors.

Different innovation paths can achieve ELV policy objectives. Each path can be expected to have a different level and a different distribution of CBs. The final outcomes of the process are largely unknown and the initial cost–benefit distribution between industrial and social actors can influence the choice of innovation path.

Some regulation instruments directly define the admissible/compulsory ways to achieve policy objectives and directly influence the choice of innovation paths, associated CBs and their distribution. Other policy instruments (economic incentives) can indirectly influence the choice of innovation path by defining the initial distribution of CBs.

Even though there have been a number of economic analyses, which have been the basis of both the EU draft Directive as well as some of the national initiatives, the estimation exercises on CBs induced by ELV regulation have been limited. The conceptual and empirical difficulties do not justify the degree of appraisal efforts, even if is not clear what should be level of analysis of a CBs when assessing a Community act. The most important instruments and provisions on ELV are being introduced at EU and national level, and are mainly based on political decisions and compromises.

**Competitiveness and competition**

An international competitiveness effect induced by ELV regulation cannot be ruled out. However, the level of the price-competitiveness disadvantage for European car-makers is uncertain. Other uncertainties arise from the globalisation of the car industry and the problem of market access.

It is likely that, in order to enjoy economies of scale and have access to all national markets, the European standard for car recycling/recyclability will become the international reference. Even in the case that industrial strategies converge to the European standard, the ‘unilateral’ adoption by the EU of stringent recycling/recyclability standards might stimulate issues in terms of access to the European market and international trading rules.
There is a possible disharmonisation effect associated with some EU directive provisions. The early formulation of FTB (1997) could have induced a variability of FTB levels which is higher than the present variability of ELV prices in different countries.

In terms of the internal market and harmonisation, the need to avoid a ‘race to the bottom’ by establishing minimum common requirements for ELV treatment facilities in all Member States can justify an EU directive.

Recycling targets can be largely different from the ‘optimal’ national targets, but they should not be differentiated without the risk of distorted competition from regulation.

**Policy recommendations**

*Environmental policy focused on product innovation should go in the direction of IPP by pursuing ‘extended product responsibility’ rather than ‘extended producer responsibility’*

Effectiveness with respect to innovation should be a primary concern of environmental policy design. A leading concept in EU environmental policy debate is integrated product policy (IPP). The focus of the ELV directive on product-making points in the direction of IPP but ELV policy is incomplete in terms of IPP. IPP and extended product responsibility for complex products cannot be pursued by a sectoral policy. Suitability of instruments and the problem of technological knowledge must first be solved as basic requirements of IPP.

*The adoption of a best practice approach can help to overcome (asymmetric) information and knowledge problems*

Limited information and knowledge creation, disclosure, and use have been a critical issue in the ELV policy-making process. The adoption of innovative approaches based on best practice analysis can help in facing evolving knowledge and asymmetric information problems in regulation-making. The development of a best practice approach must be based on the cooperative assessment of the environmental and economic impact of different technical solutions. Full disclosure of technical knowledge and consensus building about the best regulation for environmental innovation can be the ultimate goals of best practice and must shape its procedure. The independence of technical bodies involved in the process is a key factor for its credibility.

*A target-based policy approach can reduce the uncertainties of detailed regulation and economic instruments in terms of innovation incentives*

The targets adopted by the EU directive were able to define the whole profile of the innovation process. Objectives and recovery/reuse/recycling targets defined the demand of innovation to industry and also the benchmark for evaluating the effectiveness of different solutions. Once targets are made binding and enforceable, they can represent the most important innovation incentives introduced by policy. The working of detailed direct regulation and economic
instruments, instead, can have more uncertain and unpredictable impacts on innovation incentives. When \textit{ex ante} available knowledge is not enough to keep instruments working under control, the less risky choice is to base regulation on enforceable targets and minimum environmental requirements on all the operations, while leaving the industrial system to choose and self-organise the innovation path(s).

\textit{Enforceable voluntary agreements should be preferred when innovation is systemic and economic instruments can stimulate conflicting interests possibly leading to undesired innovation paths}

Systemic innovation does not reduce the leading role of the car industry in the ELV problem, but it spreads innovation tasks over all industrial actors in the chain in the pursuit of the creation of capabilities. Inter-industry agreements oriented towards innovation are the organisational instruments more directly reflecting the systemic features of innovation in ELV and they can be a necessary condition of achieving policy objectives and targets. However, they are not necessarily a sufficient condition. The main justification for inter-industry agreements is to avoid conflicts between industries that can have different interests on the problem solutions. Some industrial actors can gain from ‘undesirable’ innovation paths. The most appropriate approach in the case of ELV is the combination of inter-industry agreements with economic instruments which are self-managed by the agreement itself. Voluntary agreements for ELV might perform better than economic instruments in maintaining the cost of innovation inside industry by limiting cost transmission to consumers. Agreement enforceability overlaps with target enforceability and the two should go hand in hand.
MAIN RESULTS AND POLICY RECOMMENDATIONS

1. Knowledge about the state of the problem: selected results

The number and features of ELVs

The number of ELVs. The estimates on the number of ELVs to be treated in Member States are highly uncertain. The figure adopted in the EU directive proposal is eight to nine million ELVs (reference year, 1994) concentrated in the four largest countries (France, Germany, Italy and the United Kingdom). The figure is questioned because significant export flows of ELVs as second-hand cars are estimated from Germany as well as other countries towards non-EU countries (Eastern Europe, former USSR and North Africa). The main reason for ELV export is their relatively high value as second-hand cars in developing markets compared with their value as a source of spare parts and materials in the EU. Another factor inducing uncertainties about the number of ELVs is the adoption of car-scrapping schemes by some EU countries in recent years (Denmark, France, Greece, Ireland, Italy, Portugal and Spain). The actual number of ELVs to be treated domestically in EU countries could be 20 to 30% less than the official figure. By taking into account these ‘above-normal’ flows, the normal number of ELVs to be treated domestically can be estimated at 7.5 million units in 1998 compared with around 10 million arising from the extrapolation of official figures for 1994.

Age and material composition. The age of ELVs defines their features in terms of recycling and recovery possibilities. Different vintages have material mixes and design criteria that reflect the technologies and choices made at the time of construction. Significant changes in the car material regime occurred during the last few decades. Most cars reaching the ELV stage in 2000–05 were designed in the late 1980s and early 1990s when material mix included increasing shares of materials (e.g. plastics) which are difficult to mechanically recycle. The average material composition of new cars produced in the first half of the 1990s (i.e. ELVs of the next decade) shifted further towards polymeric materials and aluminium. The past time-profile of material innovation in car-making makes it more difficult to match the timing of the recycling targets included in the EU directive proposal. The latter is therefore a major point of contention between regulators and industry.
Recycling/recovery chains and closed-loops of materials

Knowledge about material balances of the ELV chain is still very rough and incomplete. This can represent a severe shortcoming for policy-making, especially if the latter is oriented towards LCA and Integrated Product Policy.

Materials from ELVs and car recycling rates. By applying the ‘official’ recycling rates (75 %) to the number of ELVs in the EU (8.8 million units with an average weight of 1 000 per car), the amount of materials recovered/recycled from ELVs can be estimated at 6.6 million tonnes and the amount of landfilled ASR at 2.2 million tonnes. These estimates are questionable in various respects. In addition to the uncertainties about the total number of ELVs treated in the EU, the development of ELV management schemes and voluntary agreements has already changed the recovery/reuse/recycling rates to some extent. In some countries where recovery/recycling networks between the car industry and downstream ELV treatment industries have been created, the recovery/recycling rates can be estimated at over 80 % of car weight, including energy recovery of ASR. However, these networks still do not cover all ELVs arising in their countries.

Spare parts. The car spare parts market is unevenly developed in the EU countries. It can evolve under ELV policies, and also by the increasing interest of car-makers in reconditioned spare parts for reuse. Many car-makers are developing networks for recovering and reconditioning spare parts and this can also be explained by the expectation of reuse/reusability provisions included in the EU directive. Operators in the ELV system are divided about the possibility that the developments in the spare parts market can change the whole picture for ELV management in the future.

Plastics recycling. Underdeveloped mechanical recycling of automotive plastics seems to be a major constraint on the solution to the ELV problem. Because of economic difficulties, the potential for automotive plastic waste recycling in Europe is estimated at no more than 10 % by 2006. The demand for recycled plastics in new car production is estimated at 4 % for the same year. However, the experiences of the car-makers examined in Part II suggest that higher rates are being achieved. Most car-makers are trying to exploit all the possibilities to use recycled plastics in new car models and the ongoing simplification of the plastic material regime in car-making can favour this development.

The present situation of national policies and voluntary agreements

The knowledge about the state of legislation and voluntary agreements for ELV in the EU is fragmentary, incomplete and imprecise. The study tried to reconstruct a complete picture based also on direct information from single countries.

At end-1999, 10 EU member countries (Austria, Belgium, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden and the United Kingdom) had specific regulations and/or industrial voluntary agreements for ELV. Another three countries were discussing industrial agreements (Finland and Ireland) or introducing legislation (Denmark). Six countries (Austria, Belgium, Germany, Italy, the Netherlands and Sweden) combine VAs with legislation directly
addressing ELV. Austria, France, Italy and the Netherlands introduced voluntary agreements or countrywide initiatives before the drafting of the 1997 EU directive proposal. The VAs and legislation in other countries (Belgium, Germany, Portugal, Spain and Sweden) were developed in 1997–99 during the debate on the EU directive proposal and, in some cases, after a long domestic debate.

A process of integration between industrial agreements and legislation occurred in Germany and Sweden after a long confrontation between industry and environmental policy-makers based on diverging views about distribution of responsibilities (i.e. ‘shared responsibility’, or distribution of costs over all the industries involved, versus ‘extended producer responsibility’, or financial responsibility of the car industry). The debate in Germany and Sweden was very similar to that occurring later at the EU level about the directive. The result in both countries was legislation including strong environmental and technical requirements for dismantling/shredding operations and the commitment by the car industry to apply free take-back subject to specific conditions.

In other large countries (France, Italy and the United Kingdom), ELV policy is mainly based only on VAs promoted by the car industry and involving a number of other industries. One major feature of these VAs is the absence of specific economic instruments of the FTB type and the prominence of free-market relationships. Agreements are mainly based on contractual arrangements aimed at distributing the costs and advantages arising in ELV management, with the car industry assuming the role of coordinator.

The agreement implemented in the Netherlands represents a specific approach for both its organisational framework and its economic incentives. A recycling fee is levied on new car prices and redistributed to dismantlers and recyclers. Specific mechanical recycling targets are established. The Dutch scheme is an alternative approach to that preferred by car-makers and raised a strong debate, especially about the role of market versus administered schemes in the management of ELV.

Most national voluntary agreements and/or legislation established a recovery target rate of 85% of car weight by 2002 and a total recovery target rate of 95% by 2015. There are some exceptions in terms of target deadlines. With the exception of Austria, Belgium and the Netherlands, most of the countries specify the targets only in terms of recovery rates and not in terms of recovery and recycling rates, as in the EU directive proposal, thus allowing unconstrained energy recovery of ASR. In most countries, the recovery targets are still voluntary in nature with no legislation enforcing their achievement.

At present, there are no operational proposals for the introduction of ELV regulation in Japan and the United States. However, car-makers in these two countries are developing voluntary and/or industrial initiatives to cope with the regulation developments in the EU market and the evolution of domestic waste policies.
The influence of other environmental policies on ELV

ELV management can be influenced by various environmental policies, and ELV can be considered as a systemic problem also in this respect.

Transport sectors have a significant role in the EU strategy for the implementation of the Kyoto Protocol on Climate Change. The agreement between the Commission and ACEA, the association of European car producers, on emission-efficiency improvements of new cars is considered by the Commission as an important part of EU strategy. ELV regulation might create a trade-off between car recyclability and emission-efficiency objectives by discouraging the use of lightweight materials, for example advanced polymeric materials, which have problems in mechanical recycling. Innovation trajectories in ELV impairing emission efficiency are avoided by car-makers and they claim that, if a trade-off were to arise, they would pursue emission-efficiency objectives. Whatever the practical significance of the trade-off, the ELV directive has been drafted without coordination with other environmental aspects of car production and use. This can represent a shortcoming in an Integrated Product Policy approach to environmental policy.

The development of ELV management operations can be influenced by the implementation of policies aiming to phase out leaded petrol in ‘laggard’ countries, for example Italy. The acceleration in the substitution of cars running on leaded petrol could create a wave of old cars which will need to be scrapped during the next few years with uncertain impacts on the national transposition of ELV regulation and voluntary agreement developments. Possible congestion in the treatment chain can be weighted against the possibility of economies of scale favourable to the take-off of management schemes.

Specific innovation developments at the industrial level

The analysis of single EU countries and the experience of eight leading European car-makers (Part II) supply a rich set of information on the present state of innovation in ELV management and recycling-oriented car design.

Recycling departments and competencies. During the 1990s, European car-makers created internal functions addressing ELV. They are the reference for the two main innovation directions, i.e. ELV recovery/recycling and DFD/DFR. These functionally specialised competencies and skills did not exist before in a structured form.

Dismantling and recovery/recycling networks. The creation of networks of dismantlers/shredders linked to individual car companies is one of the main directions of organisational innovation. The specific contractual arrangements between the actors involved (i.e. car-makers, dismantlers, shredders and recyclers) significantly differ from country to country and they are tailored to the specific operational context. Knowledge transfer and technical adaptation effects arise from the networks’ activities. Even in the absence of specific and legally binding regulations, dismantlers and other downstream actors are asked to perform operations under specific technical and environmental requirements.
Design for dismantling. Innovative developments in design for dismantling (DFD) are occurring in all car companies. DFD is a design tool that evolves according to experience and the specific practical problems. It may consist of small changes in the part-assembling systems or it may imply the change of some components and adaptations of other components and parts. The boundaries between DFD and design for recycling (DFR) are not clear-cut. The elaboration of IDIS, the dismantling guidelines by EuCar–ACEA, suggests that technical specifications on dismantling are undergoing a cumulative process of standardisation.

Design for recycling. DFR requires definition and measure of ‘recyclability’. European car-makers have been working for many years to develop ‘recyclability coefficients’ for the different materials and components. DFR gives rise to guidelines for component design and material selection, and manuals for internal use. Car-makers produce lists of substances and materials that are not admitted or undesired and they are part of technical specifications for component suppliers. In this way, ‘responsibility transfer’ between industries occurs. DFR is subject to various constraints from the different functions to be satisfied by car components and materials. DFR, together with DFD and LCA, is giving rise to practical consequences in the design and material composition of recent models. Car-makers are increasing the amount of recycled materials used in new car manufacturing. Recycled plastics sometimes come from recycling loops starting from ELVs in the form of ‘cascade recycling’ (i.e. the use of recycled plastics in increasingly critical components at subsequent rounds). DFR guidelines at the European level are being produced by EuCar.

Life-cycle analysis. DFR is increasingly being linked to the development of life-cycle analysis. Most car-makers are investing in LCA at the R & D level and, in many cases, they are transferring results into practical choices. The current state of LCA, however, is still weak at both conceptual and applied level. There is still arbitrariness in the choice of variables and boundaries of the process to be examined, and there are difficulties in finding neutral systems for aggregating and weighting different variables. LCA is generally still limited to specific materials or components and a car is generally considered — although not unanimously — a too complex product to have complete LCAs. Although there may be mis-measurement of some life-cycle properties, the suggestion from LCAs performed by industry is to prioritise energy-emission objectives compared to recovery/recycling objectives.

Material regime simplification. DFR pushes most car-makers to pursue a simplification of the material regime. The latter tends to favour ‘easily’ (i.e. economically) recyclable materials and seems to imply the weakening of the trends favourable to some polymers and composite materials. At present, the impact is mainly in the direction of inter-polymer substitution and it is not a reverse trend away from plastics. There is a propensity to reduce the number of polymers in favour of those having the best recycling possibilities. The increasing intensity of polymers in car material mix assumed an extraordinary significance on many grounds, including the environmental one because of their lightness. The material simplification process suggests the possibly ambiguous nature of the ELV-related innovations on environmental grounds. At the same time, it suggests that DFR can be an opportunity for the car industry to reduce the number of materials to be managed and prevent a possible over-choice of materials.
Material competition. The position of ferrous metals in car material mix seems to be somewhat reinforced by ELV regulations. Some problems for steel alloys and some non-ferrous metals can derive from the provisions on ‘heavy metals’ included in the EU directive. The substitution process can create mainly redistribution effects between different metals. The search for recyclability can favour light and recyclable materials. A case in point is aluminium. Significant research efforts are being carried out to exploit the properties of aluminium as a structural material, but they are still constrained by economic factors. Aluminium is mainly a substitute for steel or fully recycled metals, and this can reduce its contribution to overall car recyclability.

Plastics recycling. The increase of plastics recycling from ELVs has been addressed by a number of research initiatives and cooperative efforts by car-makers and plastics producers. Although they are differentiated for the different polymers, the limiting factors are largely economic in nature. The economic balances of plastics recycling are weak for many polymers due to dismantling and logistic costs that can have a great influence on total operating costs. The minimum efficient scale of operation of recycling plants for many polymers is relatively high and implies a large geographical area of procurement. An additional constraint comes from the still limited applications available for recycled polymers. The potential for cascade recycling is considered to be limited. The mechanical recycling of car polymers at the industrial scale is limited to some specific polymers from specific car components. The feedstock recycling of plastics could overcome the problems arising in the dismantling and logistics of mixed plastic streams, but it is expensive and not yet applied to automotive plastics recycling.

ASR recovery. Plastics can represent up to one third of ASR by weight and the possibility of energy and/or material recovery of ASR represents an opportunity to avoid the existing constraints on the mechanical recycling of plastics. The energy recovery of ASR in waste incineration plants and the cement industry has attracted innovative efforts and investments. The results from both industrial and research experiences suggest that energy recovery can be a rational solution from an economic point of view. Positive environmental results come from some LCAs but other studies give opposite results. Attempts are under way to separate and recover the materials in ASR (in particular non-ferrous metals and plastics) and to recycle them.

Cooperative research initiatives. In addition to R & D investments by car-makers and other industries in the chain, innovations in ELV were addressed by cooperative research efforts during the 1990s. Cooperative projects can be divided in two categories: (a) projects addressing ELV management in general; (b) projects addressing specific innovations and technical solutions. Cooperative research projects open up the possibility of common knowledge creation and transfer. Further to enabling an easier achievement of practical results, knowledge sharing creates a system of reciprocal externalities that can help the definition of possible innovation directions and their feasibility.
2. Results on the relationships between regulation and innovation

From empirical evidence, the relationships between the innovation process and ELV regulation have been identified and interpreted at different levels. In particular: (a) innovation has systemic features and tends to develop along different innovation paths that are still open, albeit constrained; (b) interactions between policy-makers and industry are significant for the innovation incentives introduced into the system; (c) specific policy instruments can be selection devices for orienting the choice of innovation paths by industry; (d) similar policy instruments can have different incentive structures according to the implied costs and benefits for different actors; (e) the social cost–benefit implications of regulation largely remain an open issue when innovation is the main response to the problem.

Systemic innovation

Observable induced innovations require the involvement of different industries operating in ELV and car-making by demanding common efforts and close cooperation. Specific innovations occurring in a specific phase (industry) of the ELV chain require innovations in other parts of the chain in order to be technically and/or economically feasible.

The systemic dimension of ELV innovation is made more significant by the requirements established by ELV policies and regulations. The latter make ELV-related innovation a process targeted at the achievement of specific objectives on decreasing the ASR to be landfilled. The ‘measurement’ of the different innovations in terms of their contribution to the targets reveals that none of them, if taken alone, seems to be able to achieve these targets. A set of interdependent innovations in different areas is thus required to solve the problem.

The car industry is the main actor in the ELV innovation process but other industries in the ELV chain have a specific innovative role to play that cannot be assumed by the automobile industry. The creation of inter-industry links is a basic innovative step. The currently uneven developments and achievements of VAs and industrial networks in the different countries do not reduce the validity of a principle of inter-industry cooperation. Uneven achievements can be explained by specific limiting factors that cannot be removed by alternative non-cooperative policy approaches.

The innovation process emerging from experiences has the feature of a knowledge and capability creation process characterised by gradual achievements, various degrees of uncertainty and learning from experience. Part of the process is company-specific, but another component is systemic and based on knowledge externalities inside and outside the industrial networks. The capability creation process is far from being complete. Car-makers and other industries are still exploring various technical possibilities, while pursuing improvements in the initiatives already in place.

The capability dimension also makes the ELV innovation process differentiated at country level. The inter-industry dimension of the ELV innovation process gives a great role to capabilities external to the car companies and the latter, especially in downstream operations (dismantling,
shredding, recycling/recovery), are necessarily defined over local (i.e. national and/or regional) economic environments.

By involving (uncertain) incremental costs that must be distributed among different industrial actors, the ELV innovation process can be critically conditioned by economic variables. Conflicts between different industrial interests and competition on various grounds accompany technical cooperation. The economic dimension can clearly influence the development and implementation of technically feasible solutions, as well as the choice between different options. The incremental cost of incremental recycling/recovery can be taken for granted, whereas the existence and timing of a positive pay-off is an open issue. DFR and related developments pave the way to competition processes between supplier industries. Policies can influence economic relationships in the ELV chain and then the innovative options that will prevail.

**Innovation paths**

Different sequences of interrelated specific innovations can be identified and grouped to define different ‘innovation paths’ that can be a reference for depicting the innovation process and the role of regulation.

*Material market creation path.* The sustainable achievement of a reduced amount of landfilled ASR is a problem of market creation for the parts, components and materials currently not recovered, reused or recycled. Market creation is focused on materials such as plastics. Some innovations are needed for the technical suitability of recycled materials for existing or new uses. In order to obtain the economic suitability of these innovations, appropriate (innovative) changes in dismantling activities are needed to have the materials in the appropriate quantities, and at the appropriate qualities and costs. The latter achievements can be greatly helped by innovations in car-making through DFD/DFR.

*Energy market creation path.* An alternative market creation path is the development of energy recovery of ASR. Innovative energy recovery technologies should be created because markets for automobile shredding fuel (ASF) are still limited. This path mainly involves new relationships between shredders and energy-consuming industries. The feedback created along the ELV chain would be less complex than in material market creation. A limited feedback on car material mix and design can be expected because the energy potential of ASR depends on plastics residuals. The pursuit of the energy recovery path, however, is policy constrained.

*Radical substitution path.* The difficulties in pursuing market creation paths might stimulate radical adaptations at the level of design and material choice, i.e. by discouraging the use of materials having weak markets for recycling. The substitution process should be considered as a reduced propensity to introduce composite and advanced materials not technically and/or economically suitable for recycling (i.e. the interruption of the trend leading to an increasing share of polymer-based materials). The radical substitution path can reduce the need for developing a ‘new’ recycling market (e.g. some plastics) and can create a problem of marginally increasing quantities in well-established recycling markets (e.g. metals).
Different actors have different preferences regarding the three paths. EU policy-makers have implicitly a strong preference for material market creation while they are adverse to energy market creation. Car-makers have a preference for a combination of energy market and material market creation, and try to avoid radical substitution and its adverse implications. Dismantlers, shredders, and material producers/recyclers have differentiated preferences for the three paths, and some of them (e.g. shredders and metal producers) might even benefit from radical substitution.

Different car-makers, industrial networks, and national situations are differently positioned along one or more of the three paths, and have different capabilities to pursue them. The three paths can be either alternative or complementary in that they can (or must) be pursued together to reach recovery/reuse/recycling targets. The environmental, technological, and economic results associated with the innovation paths are not completely known in advance.

**Interactions between policy-makers and industry**

*Regulation threats.* Expectations and threats about the introduction of regulation strongly shape the whole innovation process in ELV and have a great role in industrial strategies. Observed innovation achievements occurred before the most important regulation at EU and national level was introduced. The policy formation process had the nature of a complex impulse. National VAs and industrial networks have been a way in which industry has tried to prevent a policy impulse in the form of detailed regulation, such as the EU directive, and/or to influence its features through demonstration effects. The change in regulation expectations that occurred with the transition across the three phases reinforced some directions of innovation.

*The targets’ game.* In terms of ASR non-landfilling rates, there is a significant similarity between RRR rates established by the EU directive and national VAs or industrial networks, although the latter do not generally specify recycling targets. The target rates originated from industry-level discussions during the ‘first phase’ when little experience and actual results in ELV management were available and they reflect technological expectations and strategic propositions by industry. Regulators assumed the targets to be feasible and made them legally binding. They also introduced targets for mechanical recycling rates and imposed a target timing that involves ‘retroactivity’. Regulators also considered the VAs in force in the mid-1990s as ineffective and preferred direct regulation.

*Policy principles and technological knowledge.* The prominence of techno-economic considerations led industry to policy positions based on inter-industry cooperation (cost sharing), self-sustained recycling loops, and flexibility of technical solutions achievable by voluntary agreements. The position of regulators in the ‘second phase’ was, instead, guided by the extended producer responsibility principle (EPRP). The 1997 Directive Proposal involves product-making to a large extent and its technological and economic implications were greatly enlarged. At the same time, regulators questioned the knowledge supplied by industry as being strategic in nature, and introduced economic instruments. The involvement of product-making in a waste policy for a technologically complex product did not contribute to innovative policy
approaches. Regulation followed traditional waste-policy lines, while industry followed defensive
policy positions based on cost considerations.

The role of policy instruments

The EU directive is a complex policy package that includes a combination of heterogeneous
instruments. National-level legislation and voluntary agreements share some, but not all, of these
instruments. Significant limitations arise for the analysis of the ‘partial’ impact of single
instruments on innovation, given their extensive cross-influences. Nevertheless, specific
instruments are examined in the study in terms of their incentive properties, i.e. their ability to
influence the innovation focus of industrial actors. Specific instruments can have incentive
properties for the selection of the innovation path(s) and may work as selection devices by
discouraging some innovative options while stimulating others.

Direct regulation instruments and innovation paths

Direct regulation of dismantling. The possible incentive effect of the instrument will be mainly
a restructuring of industry to face increasing operating costs. However, the possible impact on
restructuring and organisational innovation will not be sufficient to assure that a material market
innovation path will arise. All the other innovations depicted in the ‘material market path’ are
needed, and dismantling regulation is an incomplete instrument for sustainable innovative
solutions.

Constraints on ASR energy recovery. The limitations on ASR energy recovery discourage
innovative efforts on 'energy market creation', while giving impulse to innovation investments on
'material market creation', in particular on polymeric material recycling. This policy preference
moves in the direction of inter-industry relationships and agreements, such as those promoted by
the car industry but not supported by the 1997 EU directive proposal. This policy preference is
selectively more favourable to some sectors, companies and countries. It may also be selectively
favourable to some polymers which are easier to recycle as well as other materials (e.g. some
metals), thus compensating shredders for the lost opportunity of economic recovery of ASR. A
constraint on ASR energy recovery may stimulate innovations in material recovery from ASR.

Recycling and recyclability. The EU directive proposal provides for future regulation of car
recoverability/reusability/recyclability (RRR-ability) based on amendments of the directive on
car type-approval. The provision is innovative and can be significant for innovation. Operators in
the ELV chain are still divided on the possibility of defining technical standards on RRR-ability
for a complex product such as an automobile. Technological and organisational innovations can
change the conditions at which technical and economic recyclability can match, and the concept
of materials recyclability is dynamic in nature. The definition of product recyclability (i.e. RRR-
ability of new car models) creates specific problems. Recyclability defined as a specific share of
car weight can largely depend on material mix rather than on recyclability of the materials it
contains. The same rate of recyclability can be obtained with different material mixes, designs,
and car conceptions. The definition of recyclability standards will have to face difficult choices
to avoid the risk of adverse innovation impulses. If the current state of recycling technologies and markets, for example for plastics, is taken as a reference, a high rate of car recyclability can be more easily attained by an old-conception car. A critical point could be the way current efforts on DFD/DFR are taken into consideration in the definition of standards. Furthermore, a definition of recyclability could be location-specific. In the directive formulation, reusability can be a substitute for both recyclability and recoverability. If reusability is simply defined as the existence of car models in which parts and components can be reused, the attainment of reusability is easier than both recyclability and recoverability.

**Economic instruments**

The partial influence of economic instruments on the direction of innovation may depend on their cost–benefit implications for the different actors and then on the (expected) reactions of the latter.

Free take-back, recycling fees/subsidies, and deposit-refund systems are aimed at the same externalities, address the same actors in the ‘consumer–dismantler/recycler–car-maker’ subset, and share various features. Each of the three instruments actually contains some element of the others. However, the formulation of the instrument and the level of the chain (industry, actor) at which it is applied can be significant for its impact on the distribution of costs and benefits between actors, and then for innovation responses.

FTB is an incentive instrument placed at a specific phase of the ELV chain and based on expected economic behaviours. The FTB of the 1997 EU directive proposal is a ‘free’ FTB mechanism in which dismantlers can freely establish the (negative) price for ELVs (i.e. FTB level), and the last owner will be fully reimbursed by the car-maker whatever the negative price of his/her ELV. The possibility that a great number of non-professional dismantlers will try to enjoy extra profits from this mechanism is suggested by the current structure of the dismantling industry in Europe. Furthermore, last owners (i.e. consumers) may have an opportunity cost from a ‘free’ FTB system as far as the starting situation before FTB is one in which average positive ELV prices prevail.

The possibility that ‘free’ FTB creates innovation along the market creation path cannot be ruled out. However, its focused initial cost allocation creates uncertainty about the actual innovative reactions. FTB can have different innovation outcomes: (a) innovations in recyclability and new self-sustained recycling markets; (b) little innovation impacts on car-making and design together with new recycling markets subsidised by the consumers; (c) ‘backward-oriented’ innovations, based on the interruption of trends towards advanced polymer-based materials in car-making.

A significant uncertainty is the distribution of the incentive effect along the downstream part of the ELV chain. FTB does not guarantee that the very low or zero incremental costs of incremental dismantling (dismantlers) are shared with the recovery/recycling industries (shredders, material industries) by supplying materials at very low prices.

A recycling fee/subsidy scheme might alleviate some shortcomings of ‘free’ FTB. The recycling fee/subsidy is not freely established by dismantlers and it should be established at the level of
estimated (net) incremental dismantling costs. If the recycling subsidy is distributed also to recycling industries other than dismantlers, the latter can have the incentive to create new recycling markets. Only consumers pay the financial transfer, while car-makers do not pay for ELVs. The reasons for distribution conflicts between car-makers and dismantlers/recyclers can be eliminated.

Paradoxically, the influential German car-makers are strong opponents of the Dutch recycling fee scheme while preferring a form of FTB and, at the same time, refusing the ‘free’ FTB of the 1997 Directive Proposal. This preference derives from the ways in which the two different systems could be implemented in practice rather than in principle. There are alleged adverse implications of the Dutch recycling fee as a completely administered system, and there is the possibility to arrive at ‘controlled FTB’ schemes. FTB may be subject to specific formulations that create a ‘conditional application’, as in the case of the German and Swedish schemes, that can create a cost–benefit allocation different from ‘free’ FTB.

The control of FTB can increase with its integration into voluntary agreements in which dismantlers and other industries are subject to reciprocal commitments, i.e. an implicit cost–benefit distribution. Dismantlers and recyclers in many European countries are increasingly involved in VAs with no economic incentives or with controlled forms of FTB (still not operational).

There is no empirical evidence on the working of FTB but there is on recycling fees, i.e. the Dutch scheme. The latter suggests that recycling fees could be effective in reaching recycling targets but they can be questioned on cost-effectiveness grounds. Furthermore, the fact that recycling fees are paid by the first car owner can be questioned on the ground of the ‘producer responsibility principle’. The introduction of a (controlled) FTB is more likely to maintain the problem of the costs and benefits of ELV innovation at the level of industry, thus reducing the possible role of the consumer as the ‘payer of last resort’.

**Innovation and voluntary agreements**

The incentive structure of VAs is not standardised as it derives from contractual agreements in which cost and benefits are implicit in the distribution of industrial tasks. Innovations for achieving policy objectives and targets are technically interdependent, but the related CBs can be unequally distributed. The significant incentive property of VAs is that they can put within a framework of inter-industry cooperation a set of actual and potential economic conflicts between the actors involved. They can create a system of cross-controls between industries.

Economic instruments, for example FTB and recycling fees allocating the costs and benefits of innovation to specific actors, can amplify the potential conflicts because of the difficulty of transmission of the incentives placed at a specific industrial phase to the other industries having innovation responsibilities. VAs, instead, could spread CBs and the related innovation incentives across the ELV system. Interdependency between ‘partial’ innovations inside innovation paths, in particular material market creation, creates the shared interest that all the actors can work in the most appropriate way. The weakness of one actor can impair common achievements. It is
unlikely that one industry can participate to the agreement at zero cost or enjoy extra profits at the expense of other actors.

Within the framework of VAs, the introduction of economic instruments as controlled FTB, rather than creating distribution conflicts, can have the complementary role of a second-level incentive.

The positive incentive properties for innovation, however, cannot be taken for granted for all VAs. Although all the innovative developments on ELV have emerged so far inside different forms of VAs, many agreements have not yet achieved their own objectives. Furthermore, the variety of VAs and their incomplete deployment in various countries prevent a rigorous definition of the form of agreement that can assure best incentives to innovation in practice.

The emerging regularities on *ex post* performance are weak. Even company-level initiatives or country-level agreements with no explicit forms of economic incentives and weak regulatory frameworks have been able to reach practical achievements on recycling and recovery rates. These achievements seem to be related to a large industrial participation in the agreement, to the investments in DFD/DFR by the car industry, to the successful creation of dismantling networks, and to sufficient experience allowing a deeper learning process.

The entry into force of the EU directive will change the framework of national and industrial VAs.

Member States are allowed to use VAs to comply with the key provisions of the directive (1999 Common Position). Targets will become legally binding in national transposition and will include target rates for mechanical recycling. The latter are those more closely justifying the development of agreements between different industries along the ‘material market creation’ path. Non-compliance procedures and legislation threats will be formally introduced.

Legally binding targets and legislation threats may represent a strong incentive for VAs. They will formally create an economic dividend for VAs, i.e. the estimated avoided costs of detailed regulation. The dividend will be less than desired by industry, but it can accelerate practical achievements.

With the EU directive in force, VAs will only have the role of achieving targets and other provisions in a cost-effective way. Their demonstration effect will no longer be towards EU regulators and will become the relative cost-effectiveness of different organisational solutions and different sets of instruments included in VAs. Although within the boundaries defined by different and specific national environments, this can stimulate a form of ‘race to the top’ by the different countries/companies.
Economic implications of regulation

Costs and benefits

According to the EC Treaty provisions, EU environmental policies should be submitted to some form of cost–benefit evaluation. Explicit social cost–benefit analyses of the EU directive and its provisions are not available. The accompanying notes of the 1997 directive proposal claim that, in addition to environmental benefits, the directive could have employment benefits while compliance costs for industry should be low. At country level, explicit cost accounts are available only for the Dutch scheme but they cannot be considered as social CBs. Possible costs of FTB have been estimated by the car industry. Only scant figures are publicly available on the company-level investments on DFD/DFR as well as other aspects. In general, social cost–benefit evaluation of ELV has been lacking.

Actual limitations to cost–benefit evaluation arise from the critical role of innovation in the ELV case.

The challenging evaluation of optimal targets for ELV policy based on the associated CBs has been avoided by both policy-makers and industry, and policy targets emerged from a mix of technical evaluations and strategic games. The definition of optimal non-landfilling rates of shredding residue could have pushed in the direction of differentiated targets for different countries, which is an issue to be considered in the perspective of the single market and harmonisation.

Difficulties also arise in a rigorous cost-effective analysis of different policy approaches to ELV. Each innovation path can have different total CBs and a different distribution of CBs. However, they are largely unknown and the initial cost–benefit distribution between the industrial and social actors can influence the choice of innovation path itself, also according to the possibility to shift CBs to other actors through market mechanisms during the innovation process.

Direct regulation can directly influence the choice of innovation path, for example by constraining some technological solutions, while economic instruments can have an indirect influence through initial cost–benefit allocation. The different innovation outcomes possibly associated with initial allocation and redistribution effects of FTB (see above) can illustrate this mechanism. Unless it is known which innovation path(s) will actually prevail, the definition of CB levels and distribution induced by some instruments can be very difficult and the same applies to the comparison of different policy approaches/packages.

Methodological difficulties do not justify the disregard for CB evaluation of ELV regulation and suggest that investments in appraisal could have helped to disentangle some controversial points of this regulation by highlighting economic relationships in the ELV chain.

Competitiveness and competition

The loss/gain in international competitiveness could be a significant indicator of welfare change induced by ELV regulation. ELV policies may raise costs for European industries that might
negatively influence product competitiveness provided that the EU directive has no parallel in the regulation of other major car-producing areas.

An international competitiveness effect cannot be ruled out, but its practical significance can be uncertain. One reason is the uncertain level of price-competitiveness disadvantage, while another is the weakness of price competitiveness for a differentiated product such as an automobile. Other factors of uncertainty are the globalisation of the car industry and the problem of market access.

In a global industry such as the automobile industry, it is likely that, for a specific production aspect, one single standard will prevail in order to enjoy economies of scale and have access to all national/regional markets. For market access, the prevailing standard is likely to be the most demanding one. Because of the importance of Europe and European producers in the global car industry, it is likely that the European standard for car recycling/recyclability and ELV management will become the international reference, as also suggested by the initiatives of Japanese and US car-makers.

Even in the case that industrial strategies are convergent towards the European recycling standard, the ‘unilateral’ adoption by the EU of stringent ELV-management and car recyclability standards might stimulate issues in terms of access to the European market and international trading rules. The directive provisions apply to cars ‘put on the market’, registered, and deregistered in Member States. Cars produced in non-EU countries are implicitly submitted to the same rules and technical standards as those produced in the EU.

EU regulation raises different competition issues within the framework of the internal market. The existence of rigorous arguments for the centralisation of environmental policies at the EU level can be questioned, but the harmonisation issue in ELV policies cannot be disregarded.

The need to avoid a ‘race to the bottom’ by establishing minimum common requirements for ELV treatment facilities in all Member States could be sufficient to justify an EU directive. A large part of ELV-related environmental externalities arise from treatment before ASR landfilling. Without common rules, distorted competition based on low standards can arise. A common set of minimum technical requirements can also help the development of national and industrial VAs — which, in some cases, are very demanding on dismantling and shredding facilities.

The directive targets are not ‘optimal’ RRR targets for some countries that can have difficulties (i.e. high costs) in reaching them compared with other countries, in particular for mechanical recycling. However, in the case of ELV waste, the externality is localised in the place of treatment and disposal, and differentiated targets might stimulate externality export (intra-EU flows of ELVs and ELV waste). The treatment of ELVs in locations different from those in which they arise must be prevented, and uniform targets can help the principle of proximity to prevail. Targets cannot be confidently differentiated without the risk of distorted competition from regulation.
3. Policy recommendations

From the results of ELV case studies, policy recommendations emerge that can be proposed as possibly useful for: (a) future developments in ELV policies; (b) policies on complex manufacturing products being implemented in the future, in particular electrical and electronic (E & E) waste; (c) other environmental policies involving industrial innovation. The recommendations are mainly at the level of EU regulation.

*Environmental policy focused on product innovation should go in the direction of IPP by pursuing ‘extended product responsibility’ rather than ‘extended producer responsibility’*

Technological and organisational innovation is the main solution to ELV as an environmental problem and ELV regulation is, de facto, an innovation-oriented policy. Effectiveness with respect to innovation should be a primary concern of policy design. A leading concept in EU environmental policy debate is integrated product policy (IPP). IPP is a far-reaching innovation-oriented concept whose evolution can greatly improve environmental policy effectiveness. The different definitions converge, as suggested by the Commission, to the inclusion of the following features: (a) IPP should cover the product system and its environmental effects while taking a life-cycle perspective as the lead principle; (b) IPP must involve all relevant stakeholders along the product chain. IPP is highly technical in nature and points to a responsibility principle which refers to the product over its life cycle. By attributing responsibility to all the producers involved in the product life cycle, it makes the identification of a specific ‘responsible producer’ unnecessary. IPP is therefore an ‘extended product responsibility principle’ which is more comprehensive than the ‘extended producer responsibility principle’. The EU directive on ELV addresses product-making to a large extent. Key provisions — such as limits to ASR energy recovery, limit values on certain materials, free take-back, and recyclability regulation — are directly or indirectly aimed at recyclability-oriented innovations in car-making. The focus on product-making is coherent with prevention and waste minimisation priorities and, together with the provisions on downstream ELV recovery/recycling, points in the direction of IPP. The directive, however, maintains various shortcomings in terms of progress towards IPP. First, an automobile is a service-oriented product with multiple environmental impacts that are interrelated through design and product-making choice. The directive addresses only the waste-generation aspects of a car, while it does not take fully into consideration other environmental impacts of a car as a product, for example energy-emission saving, and therefore do not embraces its life-cycle perspective (the leading principle of IPP). Second, the directive, in its 1997 version, placed much emphasis on instruments corresponding to ‘extended producer responsibility principles’ along the lines of traditional waste policy, while IPP is very open in terms of possible instruments, the latter ranging from ‘product files’ to enforceable industrial agreements. Third, the great complexity of a car as a product and ELV as a waste stream makes the information and knowledge requirements for IPP very great, while information and technological knowledge disclosure/use remains an open issue in the ELV case. The incompleteness of ELV policy in terms of IPP suggests that: (a) IPP and extended product responsibility for complex products cannot be pursued by a sectoral policy addressing one environmental impact of the product; (b) instrument selection should be very open and pragmatic and must be tailored to the features of
the production system involved, especially when product innovation is strongly systemic and inter-industrial in nature; (c) the problem of information on technological options and innovation opportunities must first be solved as a basic requirement of IPP-oriented policies.

**The adoption of a best practice approach can help to overcome (asymmetric) information and knowledge problems**

Limited information and knowledge creation, disclosure, and use have been a critical issue in the ELV policy-making process. Technological knowledge about the problem and the solutions was created and controlled by industry for the most part, and also within the framework of VAs. Policy-makers considered the use of this knowledge by industry as strategic in nature and did not accept it as a reference for regulation. As a consequence, it was not possible to use all the available knowledge in regulation-making while a detailed regulation involving product-making is very knowledge-demanding. In direct regulation/standardisation of recyclability, for example, the ambiguity of the reference concepts leaves rooms for adverse selection if the multiple technological and economic profile of recyclability is not taken into account. The recyclability standardisation process cannot avoid the involvement of industries and their technological knowledge arising from experiences, for example DFR developments. The adoption of innovative approaches based on best practice analysis can help in facing evolving knowledge and asymmetric information problems in regulation-making. The objective of best practice analysis should be the open identification of technological solutions and their evolving state in order to keep regulation open to scientific and technological progress. Partly recognised by some provisions of the 1999 Common Position, for example on heavy metals, this principle should be clearly established for environmental regulations addressing technologically complex products and processes for which innovation is the key to environmental impact reduction. It is coherent with the approach of recent regulations in some environmental areas (such as the IPPC - Integrated Pollution Prevention and Control directive). The development of a best practice approach must be based on the cooperative assessment of the environmental and economic impact of different technical solutions. Policy targets and instruments should take into account such an assessment. Many of the cooperative research efforts described for the ELV case, for example the development of European dismantling standards (IDIS), can be considered as best practice exercises from which normative indications emerge, for example how to dismantle in an environmentally safe and cost-effective way. Similar approaches can be developed through structured interaction between regulators and industry. Various points of contention between regulators and industry, for example the environmental advantages of recycling over energy recovery of ASR, could have been disentangled in a clearer way by adopting a best practice approach rather than by confrontation of diverging results from single non-mature tools such as LCA. Full disclosure of technical knowledge and consensus building about the best regulation for environmental innovation can be the ultimate goals of best practice and must shape its procedure. The independence of technical bodies involved in the process is a key factor for the credibility of the process, and appropriate standards for actors’ interactions and technological knowledge definition must be established as a preliminary requirement.
A target-based policy approach can reduce the uncertainties of detailed regulation and economic instruments in terms of innovation incentives

The EU directive placed much emphasis on policy instruments by introducing a set of specific technical regulations coupled with economic instruments. However, the targets adopted by the EU directive were able to define the whole profile of the innovation process. Recovery/reuse/recycling targets have been established at such levels that no single specific innovation can solve the problem, interrelated innovations by different industries are required, and both ELV treatment/recycling (downstream) and car-making (upstream) are involved in the process. Objectives and RRR targets then defined the demand of innovation to industry and also the benchmark for evaluating the effectiveness of different solutions. Once these targets are made binding and enforceable, they can represent the most important innovation incentives required by policy. The working of detailed direct regulation and economic instruments, instead, can have more uncertain and unpredictable impacts on innovation incentives. Economic instruments (free take-back and recycling fees) create an economic cost to some specific actors in the industrial chain and are expected to be followed by a sequence of reactions (or incentive-effect transmission) throughout the ELV chain. In complex industrial systems such as car production and ELV, the final outcomes can be sensitive to market power and cost minimisation attempts by single industries. The risk of failing impulses through incentive dissipation could be significant if the instruments are not properly designed. The use of economic instruments based on general principles should be avoided when innovation is pursued. The structure of the industrial system involved and the technical features of the problem can be very important for appropriate instrument design. Instruments of direct regulation can offer a mixed picture for innovation impulses. On the one hand, instruments such as technical and environmental requirements in the early stages of ELV treatment have harmonisation effects and avoid distorted competition based on low environmental standards. On the other hand, instruments such as restrictions on ASR energy recovery have been justified by the environmental superiority of mechanical recycling over energy recovery, as suggested by a series of LCAs, but LCAs performed by industry lead to opposite conclusions. The uncertainties on the working of instruments would suggest limiting their uses to those strictly requested and those having reliable impacts, such as minimum requirements on dismantling activities. When ex ante available knowledge is not enough to keep instruments working under control, the less risky choice is to base regulation on enforceable targets and minimum environmental requirements on relevant activities, while leaving the industrial system to self-organise contracts and economic transactions implicit to the innovation path(s).

Enforceable voluntary agreements should be preferred when innovation is systemic and economic instruments can stimulate conflicting interests possibly leading to undesired innovation paths

Policy choices on targets and product-making involvement greatly enlarged the inter-industry and systemic dimension of required innovation in ELV. Technical and economic links between downstream and upstream industries and interdependence between single innovations at different industrial stages make the identification of a single industry as ‘the responsible industry’
uncertain. Systemic innovation does not reduce the leading role of the car industry, but it spreads innovation tasks over all industrial actors in the chain. Inter-industry responsibility fits with IPP and ‘extended product responsibility’. This orientation is also supported by the strong regulation focus on ELV mechanical recycling and car recyclability that requires the most systemic innovation path among those possible. Inter-industry agreements oriented towards innovation are the organisational instruments more directly reflecting the systemic features of innovation in ELV and they can be a necessary condition of achieving policy objectives and targets. However, they are not necessarily a sufficient condition and minimum technical requirements have a role to play. In a problem such as ELV, the main justification for inter-industry agreements is to avoid conflicts between industries that can have different interests on the problem solutions. Some industrial actors can gain from ‘undesirable’ innovation paths, such as the radical substitution path, or the weakening of trends towards light and composite polymer-based materials. This outcome should be avoided. The reciprocal commitments inside VAs can define a cross-control system and a shared innovation interest between industries that prevent cost–benefit distribution conflicts which are not favourable to ‘desired’ innovation paths. Knowledge externalities and transfer between different industries inside VAs should be considered as a net benefit. To achieve the same effects, economic instruments would require certainty about their ability to create shared innovation interests through a full transmission of innovation incentives along the ELV chain. To increase the reliability of incentive transmission, economic instruments should be managed by a comprehensive administrative system, similarly to the Dutch scheme, which is sensitive to the problem of effective and efficient administration. Transaction costs may be high/low and effectiveness can be high/low according to administrative choices. The most appropriate approach in the case of ELV is the combination of inter-industry agreements with economic instruments that can be used if and when incentives to innovation appear to be weak and should be self-managed by the agreement itself. A specific requirement of innovation-oriented VAs is that they should maintain the solution at the industrial level thus preventing the consumer from being the ‘payer of last resort’. Agreement enforceability overlaps with target enforceability and the two should go hand in hand.
PART I

THE ELV PROBLEM IN EUROPE AND REGULATION DEVELOPMENTS

I.1. The automobile industry in Europe: structural developments
    Recent trends in car registrations and car-production location
    Innovation efforts by the car industry
    The international dimension

I.2. ELV in Europe: problems and trends
    I.2.1. The ELV system
    I.2.2. The ELV problem: estimates and trends
        The definition of ELV
        The number and age of ELVs
        Material composition of ELVs and new cars
        Recovery/recycling rates and chains (spare parts, metals, plastics, tyres,
        batteries, oils and operating fluids, automobile shredding residue)
    I.2.3. Industrial actors and strategies
        Automobile industry
        Material producers and recyclers
        Dismantling industry
        Shredding industry
        Consumers

I.3. National policies and voluntary agreements: overview

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    I.4.3. Other policies relevant for ELV
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        Climate change
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I.1. THE AUTOMOBILE INDUSTRY IN EUROPE: STRUCTURAL DEVELOPMENTS

Recent trends in car registration and car-production location

After the slowdown of early-1990s, new passenger cars registrations in the EU increased by about 2.3 million units from 1995 to 1998 (Table I.1). The four largest markets (France, Germany, Great Britain and Italy) account for around three quarter of the total registrations of new cars, with a very slight decrease from 1990 (76%) to 1998 (74%). Germany and Great Britain show a steady increase over the last decade, which is counterbalanced by the decrease of France and the substantial stability of Italy. These two countries have experienced, in different times, State funded scrapping schemes which contributed to slowdown the downward trend. Car-scrapping scheme worked better in Italy, probably because of the older age of the car stock. In 1997 new car registrations in Italy increased by 38.8%, while in France in 1996 the increase was "just" 10.4%. Registrations in Spain also benefited from an incentive scheme for old car scrapping during the last few years.

Table I.1
(000 units)

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<td>12,399.0</td>
<td>13,005.0</td>
<td>13,934.7</td>
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Source: adapted from ACEA data, 1999.

Total car production in the EU increased from almost 14 million vehicles in 1995 to 16 millions in 1998, with an increasing rate of change (Table I.2). The car production growth rate doubled in 1998 because of favourable factors such as the above-mentioned State-supported scrapping
schemes. The growth rate has been different for different classes of vehicles, as, for example, commercial vehicles showed more marked cyclical variations.

Table I.2
**Motor vehicles production in the European Union 1995-98**
(000 units and percent changes)

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<td>Cars</td>
<td>12,636</td>
<td>13,061</td>
<td>3.40%</td>
<td>13,451</td>
<td>3.00%</td>
<td>14,510</td>
<td>7.90%</td>
</tr>
<tr>
<td>Vans</td>
<td>1,318</td>
<td>1,393</td>
<td>5.70%</td>
<td>1,570</td>
<td>12.70%</td>
<td>1,675</td>
<td>6.70%</td>
</tr>
<tr>
<td>Trucks</td>
<td>348</td>
<td>310</td>
<td>-11.00%</td>
<td>334</td>
<td>7.90%</td>
<td>379</td>
<td>13.30%</td>
</tr>
<tr>
<td>Buses</td>
<td>30</td>
<td>32</td>
<td>4.90%</td>
<td>36</td>
<td>14.60%</td>
<td>35</td>
<td>-3.50%</td>
</tr>
<tr>
<td>Total</td>
<td>14,333</td>
<td>14,796</td>
<td>3.20%</td>
<td>15,392</td>
<td>4.00%</td>
<td>16,600</td>
<td>7.80%</td>
</tr>
</tbody>
</table>

Source: elaboration on data from various sources, 1999.

Figure I.1

The geographical concentration of car production is depicted in Figure I.1. Germany, with around 5 million cars produced, and France, with slightly more than 2.5 million cars produced, together account for half of total European production. They are followed by Spain (15%), which has only one national producer (Seat, owned by Volkswagen), and by the other two big European producers, Italy and Great Britain, with almost the same share (around 11%). Finally, Belgium is the first largest producer (8.5%) with no “national” car companies. It must be noted
that during the last decade a significant amount of car production capacity of European producers was located in Eastern European transition countries.

The data on production by plant location can suggest the degree of geographical decentralisation of car making activities (Figure I.2). The car producers considered are ten (FIAT, Volvo, Saab, PSA, Renault, Ford; BMW, General Motors, Volkswagen, Mercedes-Benz). Almost all the car manufacturers privilege their home country, where shares of total production higher than 50% are located. However, some differences do emerge. FIAT, Mercedes and Saab, for example, show the highest shares (above 80%) of total production in the home country. BMW has its production split almost equally between Germany and Great Britain, due to the recent acquisition of Rover. By having splitted its European operations equally between Germany and Great Britain, Ford does not have a “national home-base” from which to exploit particular techno-economic advantages. This picture is confirmed if Volvo, which has recently been merged, is consolidated into Ford figures. According to these figures, therefore, contrasting evidence emerges on the role of globalisation in shaping the main features of the automobile industry in Europe.

**Figure I.2**
Car production in the European Union by plant location (1995)

*Innovation efforts by car industry*

The innovative relationships between the car industry and other industries can be highlighted by indicators of the innovative effort, i.e. R&D expenditure and patenting activity for the largest EU countries (France, Germany, Italy, and the United Kingdom)\(^3\).

---

\(^3\) The analysis is largely based on Leoncini and Montresor (1999).
R&D and patents

In a medium-term perspective, R&D expenditure in the car industry has undergone a very substantial increase since mid-1980s, reaching an average indicator of 892 in 1992, with Germany and Great Britain respectively as top (1294) and worst performer (639). Along the period considered (1973-1992), the four countries have experienced an average compounded rate of growth of R&D of 11.6%. Germany has the highest growth rate (13.7%), followed by Italy (11.3%), France (10.8%), and Great Britain (9.7%).

Figure I.3 shows the share of motor vehicles R&D expenditure on total manufacturing production from 1973 to 1991, while Figure I.4 shows the R&D intensity of motor vehicles production for the four countries considered.

Figure I.3
Share of R&D in motor vehicles in R&D of total manufacturing

A first evidence is the diverging patterns in innovative effort in the different countries as far as the input indicator is concerned (Figure I.3). Germany is well above the rest of the sample, Italy and Great Britain are characterised by very similar patterns, and France is in the intermediate position. The trend in manufacturing-weighted R&D expenditure is less cyclical than that resulting from R&D expenditure alone, especially for Germany and France. Italy has a very pronounced peak in the early 1980s and between end-1980s and early-1990s. That of Italy is the most relevant change during the period, suggesting a possible catching-up, in terms of R&D intensity, of the Italian automobile industry with respect to the others.
Figure I.4
R&D intensity in motor vehicles production

Figure I.4 further confirms the evidence for Germany and France. In particular, the most notable trend is the steady increase in R&D intensity in Germany and then its diverging path compared to other countries. The cases of Great Britain and Italy are quite different: their R&D intensity is lower along the whole period, hinting how the research investments in the automobile sector are less significant than in Germany and France. More in particular, Great Britain shows a worsening of its innovative intensity starting from the mid-1980s.

Patenting activity is normally assumed to reflect the output of the innovation investments. To overcome the problems of the European patent data, we refer to the number of patents granted by the US Patents and Trademark Office during the period 1977-1995 (USPTO, OEIP/TAF Database, 1996). Because of the features of the car industry, and in particular its global-industry profile, it can be assumed that the US data reflects in a proper way also the patenting activity of European producers. To take into account scale effects, we compute a Normalised Revealed Technological Advantages index (NRTA), which is a standard specialisation Balassa index based on patent counts and normalised (see Leoncini and Montresor 1999). The results are presented in Figure I.5.

The patterns emerging are quite clear, especially in terms of increasing polarisation of the innovative results of the different national car industries. Germany is in fact the only country with positive and increasing values of the NRTA for the whole period. The other countries experience a decline in their relative technological advantages, though with different intensity. France has the steepest declining trend. Starting from positive values of NRTA in 1977 (0.10), only slightly lower than Germany (0.14), it ends up with a very wide gap. Great Britain shows more or less the same pattern as France, but with a more pronounced decrease starting from the mid 1980s, and it ends up with the lowest NRTA value (-0.15) at the end of the period considered. Italy has the most varied trajectory. It shows a cyclical upward trend that lasts until
the end of the 1980s, peaking in 1988 at the positive value of 0.05. Then Italy starts a mild decline until 1992 followed by a steep decline that reaches the minimum at the end of the period in 1995 (-0.11).

Figure I.5.
Motor vehicles NRTA, five years moving average

The international dimension

Comparative advantages

Bilateral Revealed Comparative Advantages (BRCA) for the automobile industry has been elaborated in order to look at the structural change of the international relationships\(^4\). The data on trade flows are from the OECD STAN database on Bilateral Trade (DSTI, STAN Bilateral Trade Database, 1997). The destination countries have been chosen so as to have a picture of the automobile international specialisation in the main markets, both established, such as the EU, USA and Japan, and emerging, such as South Eastern and South Western Asia (Singapore and China) and Latin America (Brazil). Table I.3 shows the values of the BRCA indicator for some years from 1975 to 1993.

\(^4\) As in the case of standard RCA, a value greater than one reveals a bilateral comparative advantage, i.e. the exports of the automobile sector perform better than those of the rest of the industrial sectors in a certain country. Hence, with BRCA we have a relative specialisation in this sector, but with respect to a specific geographical area. The opposite holds for values less than one, which indicate a relative despecialisation in automobile manufacturing with respect to a certain area.
### Table I.3. Bilateral revealed comparative advantages, 1975-1993

<table>
<thead>
<tr>
<th>Year</th>
<th>EU</th>
<th>USA</th>
<th>Japan</th>
<th>Brazil</th>
<th>Check Rep.</th>
<th>Sing.</th>
<th>China</th>
<th>OECD</th>
<th>Non-OECD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>France</td>
<td>1.64</td>
<td>0.31</td>
<td>0.32</td>
<td>0.34</td>
<td>3.03</td>
<td>1.20</td>
<td>2.27</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>1.33</td>
<td>1.44</td>
<td>3.35</td>
<td>1.14</td>
<td>0.78</td>
<td>2.19</td>
<td>0.14</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>G. Britain</td>
<td>1.11</td>
<td>0.50</td>
<td>1.04</td>
<td>0.91</td>
<td>1.20</td>
<td>2.50</td>
<td>0.42</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>1.06</td>
<td>0.76</td>
<td>0.95</td>
<td>0.67</td>
<td>2.02</td>
<td>1.64</td>
<td>2.54</td>
<td>0.82</td>
</tr>
<tr>
<td>1980</td>
<td>France</td>
<td>1.50</td>
<td>0.45</td>
<td>0.47</td>
<td>0.38</td>
<td>2.11</td>
<td>0.46</td>
<td>1.58</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>1.48</td>
<td>1.49</td>
<td>5.82</td>
<td>1.23</td>
<td>1.10</td>
<td>1.94</td>
<td>1.30</td>
<td>1.30</td>
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<tr>
<td></td>
<td>G. Britain</td>
<td>0.88</td>
<td>0.38</td>
<td>1.67</td>
<td>2.30</td>
<td>1.53</td>
<td>1.39</td>
<td>0.20</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>0.84</td>
<td>0.47</td>
<td>1.12</td>
<td>2.55</td>
<td>2.00</td>
<td>1.16</td>
<td>0.25</td>
<td>0.67</td>
</tr>
<tr>
<td>1985</td>
<td>France</td>
<td>1.30</td>
<td>0.31</td>
<td>0.30</td>
<td>1.36</td>
<td>0.75</td>
<td>0.48</td>
<td>0.67</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>1.55</td>
<td>1.31</td>
<td>6.52</td>
<td>1.38</td>
<td>1.15</td>
<td>2.12</td>
<td>0.56</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>G. Britain</td>
<td>0.64</td>
<td>0.32</td>
<td>0.81</td>
<td>1.37</td>
<td>0.82</td>
<td>1.43</td>
<td>0.59</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>0.70</td>
<td>0.15</td>
<td>0.66</td>
<td>1.48</td>
<td>1.65</td>
<td>2.90</td>
<td>0.48</td>
<td>0.40</td>
</tr>
<tr>
<td>1990</td>
<td>France</td>
<td>1.25</td>
<td>0.26</td>
<td>0.71</td>
<td>2.39</td>
<td>2.20</td>
<td>0.59</td>
<td>1.22</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>1.42</td>
<td>1.09</td>
<td>4.38</td>
<td>1.42</td>
<td>1.32</td>
<td>2.56</td>
<td>2.61</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>G. Britain</td>
<td>0.85</td>
<td>0.36</td>
<td>1.21</td>
<td>2.14</td>
<td>0.52</td>
<td>1.32</td>
<td>0.74</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>0.76</td>
<td>0.24</td>
<td>0.52</td>
<td>1.37</td>
<td>0.80</td>
<td>2.07</td>
<td>0.19</td>
<td>0.58</td>
</tr>
<tr>
<td>1993</td>
<td>France</td>
<td>1.23</td>
<td>0.23</td>
<td>0.36</td>
<td>0.56</td>
<td>1.06</td>
<td>0.44</td>
<td>1.72</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>1.38</td>
<td>0.94</td>
<td>4.26</td>
<td>1.21</td>
<td>1.08</td>
<td>3.37</td>
<td>1.97</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>G. Britain</td>
<td>0.92</td>
<td>0.28</td>
<td>1.17</td>
<td>0.95</td>
<td>0.48</td>
<td>1.64</td>
<td>0.91</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>0.64</td>
<td>0.16</td>
<td>0.59</td>
<td>2.04</td>
<td>0.96</td>
<td>1.47</td>
<td>0.28</td>
<td>0.47</td>
</tr>
</tbody>
</table>

France and Germany are the only European countries with a persistent specialisation in car export. In particular, the surge in trade flows originating from the German car industry is confirmed by the changing magnitude of the BRCA. Until the early 1980s France had the highest values while, from then on, Germany overcame France. The comparative advantages initially revealed by Great Britain and Italy turn into a progressive disadvantage in the early 1980s, partially recovered by Great Britain only in the most recent period. Also in this case, the BRCA of the two countries is decreasing, suggesting the penetration of other car producers in Europe. Moreover, Great Britain and Italy might have shifted their geographical specialisation of trade, rather than competing with France and Germany in the same markets. An example is given by the Brazilian market in which, since the early 1980s, both Italy and Great Britain acquired specialisation greater than, or comparable with, those of France and Germany.

A similar argument seems to hold for the case of Singapore where the specialisation of trade flows from Germany is greater than Italy and Great Britain. Germany appears the only competitive car producer of the four in the USA, although with a decreasing trend, and in Japan where Great Britain only reveals a certain degree of specialisation. Furthermore, in the most recent period, Germany also overcomes the previously unique and consistent specialisation of France in the Chinese market. Specific evidence emerges for the Check Republic. Data suggest increasing significance and specialisation of the German car export towards this area. Until the early `80s, France and Italy were the most competitive producers in the area while, in most recent years, Italy decreased its comparative advantages.
**Foreign direct investments**

The globalised structure of the car industry is increasingly represented by "transnationalisation" of companies. The geographical dispersion of the subsidiaries of parent company around the world is becoming so widespread that, in some cases, the actual nationality of an automobile transnational corporation could not be determined on the basis of a purely territorial criterion. These trends were already well established during the 1980s (see Leoncini and Montresor 1999) and underwent a further acceleration in the 1990s.

At mid-1990s, the major car companies were among the greatest multinationals with 13 companies among the top 100 (4 companies among the top 10) in terms of foreign assets (see UNCTAD 1996).

**Table I.4. Top 10 industries for M&As in 1998**

<table>
<thead>
<tr>
<th>Industry</th>
<th>Number of deals</th>
<th>Value (billion$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and gas</td>
<td>98</td>
<td>76.2</td>
</tr>
<tr>
<td>Automotive</td>
<td>144</td>
<td>50.9</td>
</tr>
<tr>
<td>Banking and finance</td>
<td>317</td>
<td>50.8</td>
</tr>
<tr>
<td>Telecommunications</td>
<td>231</td>
<td>50.0</td>
</tr>
<tr>
<td>Paper, printing and publishing</td>
<td>232</td>
<td>40.9</td>
</tr>
<tr>
<td>Utilities</td>
<td>111</td>
<td>39.6</td>
</tr>
<tr>
<td>Insurance</td>
<td>124</td>
<td>37.9</td>
</tr>
<tr>
<td>Business services</td>
<td>853</td>
<td>37.7</td>
</tr>
<tr>
<td>Chemicals</td>
<td>349</td>
<td>24.3</td>
</tr>
<tr>
<td>Retail</td>
<td>152</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Source: adapted from OECD (1999).

In 1998, the car industry was marked by some important mergers and acquisitions, e.g. Daimler on Chrysler. The automotive sector give rise to 144 M&As and ranked as the second sector in terms of the value of operations that reached 50.9 billion US$ in total (Table I.4). During the first part of 1999, the Ford-Volvo operation (6.6 million US$) and the Renault-Nissan operation (5.0 million US$), reinforced concentration of car industry. The trends goes on in the first part of 2000. Scenarios for the next future ranges from that of an industry dominated by very few big global companies to one in which a core of few global companies coexists with a number specialised producers in segment markets.
I.2. ELV IN EUROPE: PROBLEMS AND TRENDS

1.2.1. The ELV system

The ELV problem involves a wide set of industries, material flows, and pollution flows, and gives rise to a complex system of technical and economic relationships (Figure 1.6).

The last car-owners (i.e. consumers) are at the starting point of the ELV chain. When they decide to scrap their old cars (or are forced to scrap it because of accidents, expensive retrofitting, or other reasons), last-owner can deliver the car to collectors or dismantlers, or can deliver it to a car-dealer that delivers to a collector/dismantler. In most countries and circumstances, deregistration of the car occurs by dealer/collector/dismantlers (see Part II). The last-owner can also decide to abandon the car into the environment, thus giving rise to significant pollution problems due to pollutants dispersion and amenities loss, and possibly to an economic problem due to the subtraction of raw materials to metal recycling industries. The reason for ELV abandonment is generally considered the negative price (i.e. the net cost) the car-owner may receive when he/she delivers to a dismantler because of the low value of recoverable materials and parts and/or high dismantling costs.

Collecting/dismantling activities, be they integrated or separated businesses, perform the operations of car dismantling by taking away valuable spare-parts, operating-fluids, components whose dismantling is imposed by laws, parts and components for which some form of reuse or recycling do exist. The result is a wreck to be delivered to shredders. The extent to which valuable and non-valuable parts and components are dismantled is a key issue of the ELV problem. Until recent times, the degree of dismantling was limited to valuable spare-parts and components, while the weak regulatory framework allowed for little depollution to take place (especially for fluids and residual fuel). The weak organisational links with the recycling/material industries limited the amount and number of dismantled components and most of the latter (e.g. plastic-made components) remained a part of wrecks to be shredded. Recent regulatory provisions in single countries and EU level impose specific operations and technical conditions to fulfil at the dismantling stage (see below) while on-going organisational developments stimulate to dismantle more components to be re-used or recycled. One important problem arising at the collection/dismantling stage (but also at level of last-owner’s decision about ELV) is the export of deregistered ELV to other countries where the car is used as second-hand car (“secondary market” for ELV). Sometimes, the dismantling-cost differential, for example between Germany and Eastern European countries, can also induce to export ELVs for dismantling. Both ELV exports to foreign “secondary markets” and for dismantling at low cost do create an implicit export of pollution but also of possibly valuable materials (international externalities).
Figure 1.6. The ELV system
The shredding industry receive the car wrecks and submit them to a series of technical operations leading to the separation of materials to be delivered to material recyclers/producers. Usually, ferrous and non-ferrous metals contained in the wreck are the main (or the only) materials recovered by using well-established or innovative techniques, while some recently developed techniques allow to recover some other materials but usually at high costs (see Part III and Technical Analyses). In some cases, shredders are integrated with ferrous-metal recycling industry. The residual of shredding operation, the Automobile Shredding Residue (ASR), is generally landfilled thus giving rise to what is considered the main externality of ELV. ASR contains organic and inorganic residuals and hazardous substances, e.g. PCB, and its composition and amount greatly depends on the degree of depollution and dismantling operated by dismantlers. Usually, car wrecks are mixed with other metal-containing scraps, e.g. household appliances, in shredding operations so that ASR is mixed with other SR. By having significant calorific value, ASR can be, and in some cases actually is, recovered as energy source. Although it actually involves a small amount of ASR in Europe, the possibility of recover energy from ASR, e.g. in cement production, is explored in some industrial experience and is debated as a solution to the ELV problem (see Part II and Part III). The environmental and economic balances of ASR incineration Vs increasing mechanical recycling are important points of policy debate (see below and Part III). Some export flows of SR including ASR do exist both towards EU and non-EU countries that give rise to potential pollution export.

Automobile production requires a great variety of different materials in great amounts, and car scrapping gives rise to significant flows of materials actually or possibly recoverable/recyclable. Material producing industries are, therefore, the fundamental link between the downstream and the upstream operations in the ELV chain. On the one hand, as recyclers belonging to the secondary production segment of various materials’ industries (often integrated with primary production), material industries receive the materials from car dismantling and shredding phases and, after reprocessing, deliver materials to other industries including the car industry. The main groups of materials involved in the loop —both a closed one with the car industry and an open one with other manufacturing industries— are ferrous and non-ferrous metals, precious metals in the catalytic converters, polymers, rubber, textiles, glass, natural and artificial fibres, and wood in some instances. Recycling is an industrial activity. It produces pollution and requires energy as well as other inputs. Its environmental balance compared with primary production or other disposal solution is a vast area of technical and economic evaluation. Both secondary and primary-material producers are involved, as the suppliers of the car industry, in the choice about material mix deriving from car technologies and design developments. The latter have an overwhelming importance for the features, in particular material composition, of ELVs when they will reach the dismantling and shredding stages. After the deep changes of material regime in car production starting from 1970s, material producers are increasingly involved in car design and strongly compete in the material mix choice.

The car industry is obviously a major actor in the ELV problem. The features of ELVs depends on the whole process of car making, from conception/design to actual construction (as well as maintenance during useful life), with the obvious consequence that cars currently becoming ELVs have been designed and produced approximately 10 to 15 years ago, depending on the speed of rotation and the rate of renewal of the car stock in use. The articulation of the car
industry increased over the last two decades through the vertical dis-integration of various production stages. Car-component production largely became a separated industry, partly controlled by some specific carmaker but often supplying many carmakers. Car industry still control assembling operations and the core activities of car conception and design, and gives the main direction of the evolution of car as a product. Conception and design, however, are currently an area of intense interactions with component producers as well as material suppliers, and the latter two industries are sometimes integrated. Technical choices and constraints defining the features of ELVs are, therefore, the outcome of a complex process in which recovery/recycling of old cars is just one of the functional properties to be considered together with comfort, safety, energy consumption and emissions, and cost. Even car manufacturing gives rise to pollution and material losses, and the latter are addressed inside the carmakers initiatives on recycling (see Part II) rather than in national and EU-level policies for ELV. In addition to links with consumers that buy new cars (and with last-owners if ELV policies are in place), the car industry is linked downstream with ELV operations through the spare-parts’ market, where forms of competition and business interaction with the collector/dismantler do occur (see Part II and III).

I.2.2 The ELV problem: estimates and trends

The definition of ELV

According to the EU Directive proposal under discussion, the relevant domain of the ELV problem is represented by vehicles belonging to categories M1 and N1 defined in Annex II(A) to Directive 70/156/EEC on type-approval of vehicles and their trailers, and two or three-wheel motor vehicles (see European Commission 1997). The most important category of vehicles is represented by passenger cars. The definition of the moment in which an old car becomes ELV is still subject to different approaches in the different countries and to high degrees of subjectivity. Member countries do not have harmonised criteria to legally impose to drop the vehicle from circulation (e.g. for safety reasons), and vehicles not allowed to circulate in some countries can circulate in other countries. In France and the Netherlands, for example, the criteria for defining a car as ELV is based on the ratio between the repair costs and the car value, while in other countries the criteria leading to force deregistration are purely technical and/or administrative. Furthermore, owners can freely consider their old cars as reaching the ELV stage but other consumers, possibly in other countries, may consider the car for use. The consequences of these uncertainties on the control and monitoring of ELV number and movements across countries can be significant, and the problem is bound to remain in the next future even after the introduction of the EU Directive (see Onida 1999 for a discussion).

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5 Category M1 refers to all passenger vehicles with up to 9 seats and category N1 to commercial vehicles up to 3.5 tonnes. Two and three wheels vehicles have been excluded from specific recovery/recycling targets in the EU Directive proposal (see below in the text).
The number and age of ELVs

The figures that can be attached to the flows and activities of the ELV chain in Figure 1.6 are still estimates, sometimes very rough, for both single countries and EU as a whole. A recording system of facts and figures with a sufficient coverage is still lacking, and most part of the information available has been elaborated during the regulation-making process (see in particular IPEE 1996) and/or it is arising from the industry-level initiatives in place form early-1990s (see Part II)⁶.

A major difficulty is with the estimates of the number of ELVs actually arriving at the dismantling phase. The estimates on the number of ELV in the EU adopted in the drafting of EU Directive proposal is based on the figures of the IPEE report produced in 1996 for DG ENV to update the ADEME report of 1993 (European Commission 1993). The IPEE estimates (last year available 1994) are based on different accounting methods for the different countries based on flow or stock accounts⁷. The total number of ELV is estimated at around 8.8 million units in 1994 concentrated in the four largest European countries: 6.7 million in Germany, France, United Kingdom, Italy together, and 2.6 million units in Germany alone.

The significance of such figures for ELV as an environmental and industrial problem – and then for policy-making – is conditioned by the issue of ELVs that are de-registered in one country and are then exported to other countries to be dismantled or, more frequently, reused (international “secondary market” for ELV). In the latter case, if ELV for reuse are exported to other EU countries, the total figures on cars to be dismantled in the EU may be affected only to the extent that dismantling is partly delayed in time. If they are exported to non-EU countries (in particular Eastern European countries and North Africa), the total amount of cars to be dismantled in the EU can greatly change. As a consequence, all the other estimates about material recovery and pollution flows in the EU can be affected, and the same applies to the (future) material and pollution flows in importing countries. Something similar applies, mutatis mutandis, to de-registered ELV exported for dismantling in other countries, provided that some flow of dismantled materials and car scrap might come back to the country of origin.

Although in principle the estimation procedures referred by IPEE for some countries can take into account the import and export flows of ELV, the phenomenon can be considered as grossly underestimated. IPEE itself (1996) estimated very significant flows of ELV from Germany to Poland, France and the Netherlands in the early 1990s that are able to change the whole picture

⁶ As a consequence, complete material balances of the ELV chain in the EU or single countries are not available, and, despite the fresh information arising during the direct interview we have made, they remain a very difficult task. The elaboration of such balances, along the lines suggested by input/output analysis of material flows (and/or LCAs), could be a fundamental instrument for policy making.

⁷ The methods for the most recent years are the following: Austria: number of cars registered + number of re-registered cars - change in number of cars on the road in the year - net export of cars; Belgium: number of cars registered - change in number of cars on the road in the year - net export of second-hand cars; Germany: method of calculation not indicated for the years 1993-95; Denmark: number of cars deregistered - number of cars re-registered; Spain: method of calculation not indicated; France: method of calculation not indicated; Finland: number of cars deregistered - number of re-registered second-hand cars; Greece: number of cars registered - change of the number of cars on the road in the year - net export of second hand cars (used by Eurostat); Italy: number of cars deregistered; Ireland: same as Greece; Luxenbourg: number of car registered - change in number of cars on the road; Netherlands: direct estimate of the car to be dismantled; Portugal: method of calculation not indicated.
of ELV arriving at dismantling stage in the EU. Alternative estimates about exported ELV for dismantling and reuse are highly uncertain. From direct interviews the phenomenon emerge as a very significant one, and the export of ELV occurs to a significant extent in all EU countries for cars of all brands. Estimates for Germany suggest that out of 3.3 million cars de-registered in 1997, only 1.5 million units were dismantled in the country. The significance of down-selling for reuse abroad is suggested also by the age-structure of de-registered cars in Germany, which is biased towards young cars belonging to high volume classes, and by direct estimates by some car producers on available ELVs of their own make in Europe (see Part II).

Even by assuming that the phenomenon in other EU countries is not so significant as in Germany — but it is well-known in Italy and France and is claimed to apply also to the Netherlands — it could be guessed that the actual number of ELV to be dismantled in EU countries could be 20% to 30% less that the officially adopted figure. A summary of available information is presented in Table I.6 where the 1994 estimates by IPEE and figures for 1997/98 arising from direct interviews are compared. The figures for 1997/98 are influenced by the “wave” of ELVs caused by the scrapping schemes adopted in some countries (especially in France, Italy, and Spain) that can alter temporarily the “normal” flow of ELVs (see below for a discussion). In the case of Italy, for example, the data for 1997 include 1,150,000 ELVs caused by the scrapping incentives (650,000 in 1998), and in the Renault dismantling network alone the impact can be estimated at no less than 200,000 cars (personal communications). Between 1995 and 1998, the registrations of new cars in EU15 increased by 2.3 million units and the new car production increased for the same amount (see Tables I.1 and I.2). It is not unreasonable that, by extrapolating IPEE estimates to 1997-98, an “official” estimate of 10-11 million ELVs would result that can be compared with the 7.5 million units in the second column of the table.

In the absence of precise statistics, the EEA (1999) estimates at 6 to 10 million tons the ELV ”waste” in the EU in 1996 as realistic, corresponding approximately to 6 to 10 million units of ELVs. EEA projections (EU12, excluding former Eastern Germany) suggest an increase of 17% of the number of ELVs by 2000 compared to 1995 (at approximately 12 million units) and an increase of 35% by 2010 up to 14 million units.

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8 Personal communications even suggests a number of ELVs actually arriving at dismantling of around 4 million units in the EU in recent years, i.e. less than half of the “official” figure.
Table I.6.
Estimated number of ELVs for dismantling in EU countries

<table>
<thead>
<tr>
<th>Country</th>
<th>IPEE estimates* 1994</th>
<th>Estimates of ELVs available for domestic dismantling ** 1997(a) or 1998 (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>179,000</td>
<td>90,000 (a)</td>
</tr>
<tr>
<td>Belgium</td>
<td>236,530</td>
<td>300,000 (a)</td>
</tr>
<tr>
<td>Denmark</td>
<td>140,500</td>
<td>120,000 (a)</td>
</tr>
<tr>
<td>Finland</td>
<td>80,000</td>
<td>110,000 (b)</td>
</tr>
<tr>
<td>France</td>
<td>1,800,000</td>
<td>2,000,000 (a)</td>
</tr>
<tr>
<td>Germany</td>
<td>2,600,000</td>
<td>1,500,000 (b)</td>
</tr>
<tr>
<td>Greece</td>
<td>64,522</td>
<td>50,000 (a)</td>
</tr>
<tr>
<td>Ireland</td>
<td>64,541</td>
<td>85,000 (a)</td>
</tr>
<tr>
<td>Italy</td>
<td>1,100,000</td>
<td>1,800,000 (b)</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>32,460</td>
<td>30,000 (a)</td>
</tr>
<tr>
<td>Netherlands</td>
<td>287,000</td>
<td>270,000 (a)</td>
</tr>
<tr>
<td>Portugal</td>
<td>150,000</td>
<td>120,000 (a)</td>
</tr>
<tr>
<td>Spain</td>
<td>589,265</td>
<td>550,000 (a)</td>
</tr>
<tr>
<td>Sweden</td>
<td>125,224</td>
<td>164,000 (b)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1,400,000</td>
<td>1,900,000 (b)</td>
</tr>
<tr>
<td>Total EU15</td>
<td>8,849,042</td>
<td>9,089,000 (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7,589,000 (2)</td>
</tr>
</tbody>
</table>

10,349,042 (3)

* For method of calculation see the text and footnotes. ** From direct interviews to carmakers and professional associations, and information from Org-Consult.

Key to estimates of total number: (1) Total for EU15 from available information for 1997 or 1998; (2) As above, but subtracting 1,500,000 ELVs considered as the “above-normal” flow due to scrapping schemes in France, Italy and other countries (as well as individual carmakers) in 1997-98; (3) IPEE estimate for 1994 augmented by 1,500,000 ELVs to reflect an increase of 2,300,000 new car registrations in EU from 1995 to 1998.

Source: IPEE (1996) and calculations from personal communications.
The main cause of ELV export as second-hand cars is generally the high price of ELV in the international "secondary market" compared to its value as a source of spare-parts and materials at the dismantling stage. The reason for dismantling ELV in other non-EU countries, instead, is the low cost of dismantling operations, which are generally labour-intensive, the less-demanding regulations, and the lower costs of ASR landfilling. The consequences of ELV export for both reuse and dismantling have been felt during the 1990s as a strong pressure on dismantling/landfilling capacity in some Eastern European countries together with the concern by shredders and metal recyclers, especially in Germany, about the erosion of an important source raw materials. During the last few years, some Eastern European countries (e.g. Poland) intensified controls and regulations on ELV inflows and domestic treatment, while the problem had a significant role in accelerating both national policies and regulations, in particular in Germany and at the EU-level (see below and Part II). Some of the provisions now being introduced in national regulations are addressed to control and discourage export flows and the same applies to destruction certificates and deregistration procedures in EU Directive. Furthermore, the problem of economic convenience at the root of ELV export can have a significant role in the debate on policy instruments, in particular on economic instruments (free take-back, recycling fees) involving last owners’ and dismantlers’ behaviour (see Part II and III).

During the last few years, the number of ELV in the EU has been influenced by the car-scrapping incentive schemes implemented in some countries, i.e. France, Italy, Spain, Denmark, for both economic and environmental reasons (i.e. to revitalise industrial production and introduce more energy- and emission-efficient new cars). The implications of scrapping schemes are twofold. The first effect is that they influence the time-profile of ELV flows by creating a short-term wave possibly followed by a drop in subsequent years. Some figures on the significance of these effects —whose impact on dismantling and shredding capacities is also influenced by the possibility to stock ELVs and materials— are reported for France and Italy in Part II. The second effect is that scrapping schemes influence at the margin the features, e.g. the age and material composition, of the present car stock and, then, of ELVs in the next few years. While car scrapped at present have weight and material composition reflecting the criteria of 10 to 15 years ago, new cars substituting for them are heavier and contains greater shares of non-easily recyclable materials (see below). As a consequence, the stock of potential ELV in 2006-2012 could be relatively more heavy and intensive of non-easily recyclable materials than would have been without the country-level scrapping schemes of 1995-97. The significance of these effects, however, is very difficult to quantify. A new scrapping-scheme effect will arise in the next few years with the deadline established by the Commission in December 1999 for leaded gasoline phasing-out in some “laggard” countries, i.e. Italy, Spain, and Greece, that might impose extensive car renewal processes (see Par. 1.4.3).

9 The same applies to ELV directly exported by the last owner, given the relatively low price he/she can receive for the car from collector/dismantler.

10 Some complex effects have arisen for the spare parts market: given that scrapped cars are those older than 10 years that demand spare parts more than younger cars, their scrapping both reduced demand and increased supply of spare parts (personal communications from Daimler-Chrysler).
The average age of ELVs is estimated at approximately 10-12 years in the EU but with a significant variability among countries —each of them having a specific age distribution of the car stock—and, in some of them, cars are very old, e.g. Italy 14-15 years before scrapping schemes, and Sweden up to 17 years. The age of car reaching the ELV stage is important for technical and economic potential at dismantling/shredding stages and thus for potential impact on pollution and waste. Different material mix, assembling criteria and average weight are associated to different vintages. The building criteria of each vintage can be modified by car makers through design adaptations —and then can be influenced by the policy requirements and the initiative for recyclability currently under development (see Part II and III). But the latter are felt at dismantling/shredding stages with a time lag that depends on the frequency distribution of ages and rotation speed of the car stock in a probabilistic way. Most of the car reaching the ELV stage in 2005 were designed in 1980s and early 1990s with a possibly little influence of the policy developments on car recyclability under way, and with a possibly high share of materials (e.g. some polymers) with low recycling potential. This is one of the reasons for the conflicts about the timing of recovery/recycling targets in the discussion of the EU Directive proposal (see below).

Although ELVs abandoned into the environment (i.e. non-delivered to collectors/dismantlers) is one of the main factors behind ELV policy development, very few figures are available on the phenomenon. IPEE (1996) recorded information from Germany (11,000 vehicles in Brandeburg 1994), Italy (5% of all ELVs, guess estimate), Sweden (from 1,500-5,000 to 30,000-40,000 according to different sources), the United Kingdom (20,000-30,000 in early 1990s). The estimates seems to be unreliable for producing a general picture but it is clear, also from direct interviews, that abandoned ELVs are many in various countries and regions, e.g. Southern European regions.

**Material composition of ELVs and new cars**

The environmental and economic impact of ELV treatment is influenced by material regime prevailing in car production as well as by design and conception elements, e.g. assembling and car weight, that have consequences on the share and the amount of recoverable/reusable/recyclable materials.

Over the last few decades, a significant change in car material regime occurred based on the shift towards materials that can have problems in mechanical recycling, in particular some polymer-based composite materials, together with other materials that are light and easily recyclable.

In 1965 a new European car contained on average 82% of ferrous and non-ferrous metals (2% aluminium) and 2% of plastics in terms of total weight. In mid-1980s, the content of ferrous and non-ferrous metals averaged 74-75% (with aluminium at 4.5%) and plastics were estimated at

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11 The latter can be temporarily altered, for example, by the above mentioned scrapping schemes.
8-10% of total weight (Table I.7)\(^{12}\). The data for 1985 can be considered as representative of the material composition of car becoming ELVs in the second half of 1990s.

The average material composition of new cars produced in the first half of 1990s - that can be representative of ELVs in the next decade - shifted further towards materials other than metals, excluding aluminium (Table I.8).

Despite the uncertainties that can be associated to estimates for European averages, specific data on material composition of cars of different brands and models (see Part II) confirm the increase of plastics and aluminium in the material mix of car produced in recent years. The two trends are very significant for ELV policies and related innovation but they have different implications.

Table I.7.
Material composition of cars produced in 1965 and 1985 (current ELVs)
(percent of total weight)

<table>
<thead>
<tr>
<th>Material</th>
<th>1965</th>
<th>1985*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and steel</td>
<td>76%</td>
<td>68%-75.6%**</td>
</tr>
<tr>
<td>Lead, copper and zinc</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>2%</td>
<td>3%-4.5%</td>
</tr>
<tr>
<td>Plastics</td>
<td>2%</td>
<td>8%-10%</td>
</tr>
<tr>
<td>Glass, rubber, others</td>
<td>16%</td>
<td>13.5%-14.5%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

* Two sources are presented for 1985 to take into account the very different data available. ** Iron and steel + lead, copper and zinc.
Source: adapted from IPEE (1996) and Montedison (1993).

Table I.8
Material composition of European cars produced in 1990/1994

<table>
<thead>
<tr>
<th>Material groups</th>
<th>1990/94</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel, cats iron, zinc copper and lead</td>
<td>65%-67.5%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>5.5%-8%</td>
</tr>
<tr>
<td>Plastics</td>
<td>9.1%-10%</td>
</tr>
<tr>
<td>Rubber</td>
<td>5.5%-6%</td>
</tr>
<tr>
<td>Other materials (glass, fibres, paints, etc.)</td>
<td>9.4%-14%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>


\(^{12}\) According to data from PRAVDA 2 (see Part II), the share of plastics in car currently reaching the ELV stage in Germany is about 6% of total weight.
From 90 to 100 kg of plastics are currently used in a new car, compared with the 50 kg estimated in the 1970s, and they include up to 21 different polymer types (see Table I.9). According to experts, there can be up to 1,000 plastic parts in a single car model (APME 1996). Each polymer can be considered as tailored to meet specific safety, economic, aesthetic requirements but some degree of substitutability exists among different polymers and polymeric families to perform the same functions. This very complex plastics regime gives rise to severe constraints to an extensive recycling of plastics materials in ELVs, especially when polymers are mixed together or with other materials in composites (see Technical Analyses).

### Table I.9.
**Plastic types and weights in an average European car**

<table>
<thead>
<tr>
<th>Part</th>
<th>Plastic type</th>
<th>Weight in an average car (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat foam</td>
<td>PUR</td>
<td>9.45</td>
</tr>
<tr>
<td>Fuel tank</td>
<td>PE</td>
<td>6.44</td>
</tr>
<tr>
<td>Bumpers</td>
<td>PP</td>
<td>5.65</td>
</tr>
<tr>
<td>Undercarpet backing</td>
<td>PUR</td>
<td>3.80</td>
</tr>
<tr>
<td>Carpets</td>
<td>PET</td>
<td>2.74</td>
</tr>
<tr>
<td>Underbody protection</td>
<td>PVC</td>
<td>2.40</td>
</tr>
<tr>
<td>Bumpers</td>
<td>PC+PBT, PUR</td>
<td>2.25</td>
</tr>
<tr>
<td>Dashboard</td>
<td>PP</td>
<td>2.25</td>
</tr>
<tr>
<td>Trim</td>
<td>PP</td>
<td>2.25</td>
</tr>
<tr>
<td>Rear shields</td>
<td>PP</td>
<td>2.08</td>
</tr>
<tr>
<td>Dashboard</td>
<td>ABS</td>
<td>1.65</td>
</tr>
<tr>
<td>Trim</td>
<td>ABS</td>
<td>1.63</td>
</tr>
<tr>
<td>Non identified SMC/BMC</td>
<td>SMC/BMC</td>
<td>1.61</td>
</tr>
<tr>
<td>Textiles</td>
<td>PET</td>
<td>1.32</td>
</tr>
<tr>
<td>Cushion overlay</td>
<td>PUR</td>
<td>1.13</td>
</tr>
<tr>
<td>Bumper fascia</td>
<td>SMC/BMC</td>
<td>1.13</td>
</tr>
<tr>
<td>Battery</td>
<td>PP</td>
<td>1.10</td>
</tr>
<tr>
<td>Dashboard</td>
<td>PVC</td>
<td>1.08</td>
</tr>
<tr>
<td>Other parts</td>
<td>All materials</td>
<td>50.04</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>100.04</td>
</tr>
</tbody>
</table>


Aluminium share of car weight is currently estimated at 6% (see EAA 1996) and, according to producers, the quantity of aluminium in an average European car can double in the next decade. Aluminium is fully recyclable without loss of properties, and a well developed secondary markets for aluminium exists. The transport sector is the most important market for secondary aluminium (see Table I.10) and two-thirds of aluminium in average European car is estimated to come form recycling. The estimated recovery rate of aluminium from ELVs is around 95%. The closeness degree of the loop for aluminium is therefore relatively high. However, the possible contribution of increasing aluminium share to ELV overall recycling rates crucially depends on the material
for which it is substitute. In general, the trend is towards substitution for other fully-recycled materials, as steel, and this implies a relatively low contribution, especially if the recycling targets are specified in terms of percentage of total weight (see Part III for a discussion).

Table I.10.
Main markets for aluminium in Europe, 1995

<table>
<thead>
<tr>
<th>Sector</th>
<th>Extruded products</th>
<th>Rolled products</th>
<th>Secondary aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>13%</td>
<td>8%</td>
<td>75%</td>
</tr>
<tr>
<td>Buildings</td>
<td>51%</td>
<td>12%</td>
<td>7%</td>
</tr>
<tr>
<td>Packaging</td>
<td>-</td>
<td>45%</td>
<td>-</td>
</tr>
<tr>
<td>Engineering</td>
<td>15%</td>
<td>10%</td>
<td>14%</td>
</tr>
<tr>
<td>Others</td>
<td>21%</td>
<td>25%</td>
<td>4%</td>
</tr>
</tbody>
</table>


A trend that can influence the scale of the ELV problem in the future is the increase in average car weight. Under the increasing requirement for performance, comfort, and passive/active safety, the increase of car weight reached 20% between 1987 and 1995 for some car models (see IPTS-JRC 1996). Not necessarily the higher weight does imply a corresponding increase in the non-recoverable share of ELV (and then of ASR). Additional weight can be based on easily reusable/recyclable materials and design criteria for heavier cars might be more favourable to recycling/reuse. The problem of increasing weight seems to be relatively more significant for energy consumption and emission performance, and can adversely counterbalance the favourable impact of new fuels and engine technologies (see Figure I.7). In this perspective, the increasing share of plastics and light metals counterbalances the trend towards increasing car weight and it is a key area of innovation (see EuCar 1994).
Recovery/recycling rates and chains

The picture about current recovery/reuse/recycling of ELVs in the EU is very uncertain. By “recovery” we mean the “non-disposal” of ELV waste, and then reuse of parts, components and materials, mechanical recycling of materials, and energy recovery of ELV waste (ASR). The current rate of ELV reuse/recycling is generally estimated at 75% of car weight for both single countries and the EU as a whole. There is not a system of direct recording of the reuse/recycling rates in the single countries, and the “officially” assumed 75% rate corresponds to the current ferrous and non-ferrous metal content of European cars, under the assumption that almost all metals in ELVs are actually reused/recycled at the dismantling and shredding phases. The remaining component, i.e. the residue of the shredding activity (ASR), is estimated at 25% of car weight and, given the small amount of ASR incinerated for energy recovery in most countries, it is considered to represent the part of ELV disposed-off by landfilling.

By assuming the above recovery/disposal rate, an average European car weight of 1000 kg, an estimated number of 8.8 million ELVs in the EU, than it can be estimated that 6.6 million tonnes of materials are reused/recycled from ELVs and 2.2 million tonnes of ASR are landfilled in the EU in mid-1990s (see also IPEE 1996). The problems with the estimated number of ELVs referred above can greatly change the picture for both the quantities of reused/recycled materials and landfilled ASR. Furthermore, with the development of industrial networks for

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13 The ELV Directive proposal define as “waste” all the weight of ELVs, following Art 1(a) of Directive 75/442/EEC, and define “recovery” and “disposal” in accordance with the Annex IIB and IIA of the same Directive. Recycling is defined as mechanical recycling only, excluding energy recovery. Hazardous substances are defined following Directive 67/548/EEC. The IPEE study of 1996 considers only ASR as ELV waste, and we will maintain the same definition.
recovery/reuse/recycling currently in place in various countries, the actual recovery rate (including reuse/recycling/energy recovery) can be considered to be increasing to some extent. For example, the Renault system is reported to give rise to a recovery rate of 83.7% (including energy recovery of ASR); the FARE system of FIAT is reported to reach a recovery rate over 82%; the ARN system in the Netherlands is reported to reach 86% recycling rate (with no energy recovery but recovery of metals is based on assumptions) (see Part II). Estimates for Germany (personal communications) suggest that the average weight of a ELV can be 980 kg and the ASR can be around 152 kg, thus giving rise to a recovery rate of 86% and ASR landfilling of 16% of total weight. Even though industrial networks are able to achieve recovery rates well-above 80%, they do not still cover the treatment of all ELVs in their countries (except the Netherlands), and the 75% rate cannot be considered as obsolete in defining the state of ELVs “non-landfilling” at the EU level.

Even the 75% reuse/recycling rate can be considered high compared with other industrial products, and it corresponds to a flow of raw materials which is significant for various industries, including those supplying the car industry itself. The most important categories of parts and materials are: spare parts and reusable components; ferrous and non-ferrous scrap; recyclable plastics; used tyres; used batteries; used oils. Available information for these categories at the European level is summarised below. The main data for other materials (i.e. glass, textile, catalytic converters, others) are summarised in IPEE (1996) and Zoboli (1998).

Spare parts

The recovery of spare parts from ELVs is typically the main business of collectors/dismantlers and largely depends on the conditions of the ELV itself. In average conditions, recoverable spare parts can represent about 20% of the car weight (personal communications). The market for automotive spare parts in Europe is very complex and a comprehensive picture is difficult to draw. A study by Partslife Recycling System (1999) highlights a turnover of 35 billion DM but it is estimated that, in Europe, only 10% of spare parts are recovered while the corresponding share for the United States is estimated at 40%. Market penetration of reconditioned spare parts is considered high in Germany, Switzerland, Austria and Northern European countries, whereas it is considered very low in Southern European countries. The economic significance of spare parts reconditioning/reuse is considered to reach a maximum after the production of a model has stopped and the production of new spare parts is at a loss. The environmental significance can be very high given the saving of materials and energy/emissions, although resources for collection, transportation and operations (reconditioning) must be considered. The safety considerations about spare parts can be high for some of them and stimulated a specific attention by recent regulations in some countries. Various carmakers are developing organisational solutions for the reconditioning and reuse of spare parts arising from maintenance operations at the dealer shops as well as those arising form ELV treatment in their industrial networks (see Part II).
Metals

Ferrous and non-ferrous metals represent the other most important stream of materials form ELVs. At the same times ELVs represent an important source of raw materials for the ferrous and non-ferrous metals industry. Estimates for Germany (personal communications) suggest that, out of a 980 kg of ELV weight entering the dismantler, 650 kg (66.3%) remain as car wreck to be delivered to shredders. The latter are estimated to recover around 400 kg of metals per car or 41% of initial weight. By applying this share to the official number of ELVs (8.8 million units) at a unit weight of 980 kg, the total amount of ferrous and non-ferrous metals from ELV can be 3.5 million tonnes. This can represent around 5-7% of total apparent consumption of both ferrous and non-ferrous scraps in the EU but does not take into account the possible net inflow of metallic scraps from ELV from extra-EU countries. According to BIR estimates for 1996, ELVs can supply up to 10% of total apparent consumption of ferrous scrap in EU, and the corresponding share for non-ferrous scrap could be about 15% (personal communications). Although no general estimates are available, a significant share of metals used in new car production comes from recycling and, partly, form ELVs’ recycling (closed-loop of materials).

Plastics

As mentioned above, the recycling of plastics form ELVs is still underdeveloped and its possible development is the subject of extensive experiences in the industrial networks for ELVs as well as research efforts by the plastics-producing industry. According to APME (1996), the amount of plastic waste from ELVs in Europe was 500,000 tons in 1996, which reflects the design and material composition prevailing in the first part of 1980s. It is expected to increase to 850,000 tons in 2015 when the current materials composition, more intensive of plastics, will be reflected in ELVs. Other APME estimates (APME 1998), suggest that the post-user plastic waste in the automotive sector in Western Europe was 796,000 tonnes in 1997, which represents 4% of total 17,454,000 tons of plastic waste and can be compared to 11,102,000 tons arising from the municipal waste sector (see APME 1998) (Table I.11).

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14 By using a different method of calculation, IPEE (1996) arrives at an estimated amount of 3,860,000 tons of ferrous metals from ELVs in 1994. With the same method, by considering non-ferrous metals to represent 5% of total ELV weight, the amount of non-ferrous scrap could be around 275,000 tons.
Table I.11.
Post-user plastic waste in Europe by sector and recovery technology, 1997
(000 tonnes/year)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Incineration</th>
<th>Landfilling</th>
<th>Feedstock recycling</th>
<th>Mechanical recycling</th>
<th>Export to be recycled</th>
<th>Energy recovery</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>-</td>
<td>220</td>
<td>-</td>
<td>97</td>
<td>1</td>
<td>9</td>
<td>327</td>
</tr>
<tr>
<td>Automotive</td>
<td>-</td>
<td>610</td>
<td>-</td>
<td>66</td>
<td>1</td>
<td>119</td>
<td>796</td>
</tr>
<tr>
<td>Building/construction</td>
<td>-</td>
<td>860</td>
<td>-</td>
<td>44</td>
<td>-</td>
<td>-</td>
<td>904</td>
</tr>
<tr>
<td>Distribution</td>
<td>26</td>
<td>2,320</td>
<td>-</td>
<td>756</td>
<td>-</td>
<td>339</td>
<td>3,441</td>
</tr>
<tr>
<td>Electric and electronic</td>
<td>-</td>
<td>792</td>
<td>-</td>
<td>22</td>
<td>-</td>
<td>70</td>
<td>884</td>
</tr>
<tr>
<td>Municipal solid waste</td>
<td>199</td>
<td>8,063</td>
<td>334</td>
<td>455</td>
<td>13</td>
<td>2,038</td>
<td>11,102</td>
</tr>
<tr>
<td>Total</td>
<td>225</td>
<td>12,865</td>
<td>334</td>
<td>1,440</td>
<td>15</td>
<td>2,575</td>
<td>17,454</td>
</tr>
</tbody>
</table>

Source: adapted from APME (1998).

Only 66,000 tons (8.3%) are estimated to be recycled out of the plastics waste arising in the automotive sector in Europe. An estimated 119,000 tons (around 15%) of automotive plastics’ waste, generally as a part of ASR, are recovered as energy source. Most part (610,000 tons or 76.6%) is currently landfilled as a component of ASR. The above figure can be compared with the officially estimated amount of 2.2 million tons of ASR to guess a share of plastics in ASR in Europe at 30%-40% of weight. The various technical possibilities (mechanical recycling, feedstock recycling, energy recovery) for increasing the recycling/recovery rates and the practical achievement in some industrial experiences are analysed in Part II. In some of these experiences, one of the main roads to recycling increase is the use of recycled plastics in new car parts and components (e.g. “cascade recycling”). However, a realistic potential for plastics’ waste recovery in the automotive sector in Europe is estimated by APME (1998) at no more than 10% by 2006, given the imbalances between materials collectable and market demand. The potential demand of recycled plastics for making automotive parts to be used in new cars is estimated at 4% for the same year but the developments occurring in major car companies suggest that a higher share can be achieved (see Part II).

Differently from post-user (ELV) plastic waste, there is a significant development in various countries of recycling of “new plastic scrap” arising during components’ and parts’ manufacturing, and the latter is included in the organisational experiences on ELV and recycling by some carmakers in Europe (see Part II). The advantage of “new scrap” is obviously the purity and homogeneity of materials, the regularity of flows, and the low costs of collection (mostly a joint-cost).
Tyres

Tyres from ELVs represent only a part of the total stream of used tyres during the useful life of the vehicle (i.e. the last five tyres), and they are estimated to represent 10% of total used tyres arising yearly in the EU (personal communications). Used tyres are removed from ELVs before shredding for a large part, and the recent regulation provisions about tyres removal from ELVs (national level and EU Directive proposal) should push removal towards a 100% rate. These developments, however, should not change substantially the general problem of recovery and recycling of used tyres which is subject to specific developments (see European Rubber Journal 1998). Generation and recovery of used tyres in nine EU countries in 1996 is illustrated in Table I.12.

The share disposed-off by landfilling is estimated at 28% compared to 34% in 1994, but it reported to be very high in countries as France (45%), Italy (40%), and Spain (75%). A pressure towards scarp tyres recovery comes from EU directives, e.g. landfill directive that is banning landfill for tyres by 2000 and shredded tyres by 2005, as well as by national regulations and voluntary agreements mainly pursuing the same goals of zero landfill (see European Rubber Journal 1998).

Different recovery technologies are subjects to various initiatives, innovations and debates about their relative advantages in economic and environmental terms, also in connection to the developments of other sectors of waste management, e.g. refuse-derived fuels. Further to the small share of scrap tyres exported, a significant part of used tyres are retreaded for reuse, at a rate between 17% to 20% in most countries with the exception of the 60% rate in the Netherlands, giving rise also to significant extra-EU export\(^\text{15}\). About 12% of scrap tyres are recycled mechanically giving rise to materials used in different applications. The share of mechanical recycling is increasing but the market potential could be at most 25% of total if favourable policies will not be implemented. Significant potential is attributed, albeit with some constraints, to the used of granulated rubber in road construction materials. The most important use of scrap tyres at present is energy recovery. During the last few years, the use of granulated tyres as a substitute for coal in cement kilns rapidly developed. In some countries, a significant direction of development is the use of tyres in combination with municipal waste for RDF. The corresponding technologies are still under improvement but they can offer a very large potential (see also Part II).

\(^{15}\) The latter are sometimes flows of low-safety retreated tyres towards LDCs (personal communications).
Table I.12.
Amount and recovery of used tyres in nine EU countries, 1996

<table>
<thead>
<tr>
<th>Country</th>
<th>Generation (000 tons)</th>
<th>Retreads (%)</th>
<th>Recycled (%)</th>
<th>Energy (%)</th>
<th>Landfill (%)</th>
<th>Export (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>354</td>
<td>20</td>
<td>16</td>
<td>15</td>
<td>45</td>
<td>4</td>
</tr>
<tr>
<td>Germany</td>
<td>603</td>
<td>17.5</td>
<td>11.5</td>
<td>46.5</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Italy</td>
<td>330</td>
<td>22</td>
<td>12</td>
<td>23</td>
<td>40</td>
<td>2</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>378</td>
<td>31</td>
<td>16</td>
<td>27</td>
<td>23</td>
<td>2.5</td>
</tr>
<tr>
<td>Belgium</td>
<td>44.8</td>
<td>20</td>
<td>10</td>
<td>30</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Finland</td>
<td>27</td>
<td>9</td>
<td>4</td>
<td>25</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Netherlands</td>
<td>25</td>
<td>60</td>
<td>12</td>
<td>28</td>
<td>0</td>
<td>na</td>
</tr>
<tr>
<td>Spain</td>
<td>202</td>
<td>20</td>
<td>0.5</td>
<td>na</td>
<td>75</td>
<td>na</td>
</tr>
<tr>
<td>Sweden</td>
<td>55.6</td>
<td>5</td>
<td>9</td>
<td>71</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>


**Batteries**

Battery represent on average 1.4% of ELV weight and, as in the case of tyres, are just one part of the total used batteries arising during useful car life. If not reusable when removed from ELVs, they are treated to recycle lead and their contribution to the overall ELV recycling rate is already accounted for by the data on non-ferrous metals referred above. Lead from batteries represent a large part of the raw material for secondary lead production, which is very important compared to primary production. There are not figures about the possible extent of non-removal of batteries from ELVs, and then about the possible impacts of acids and other harmful components on the composition of ASR\(^{16}\). Various countries have introduced specific regulations and voluntary agreements for batteries’ collection and recovery, in particular after a specific EU Directive. Also plastic cases containing batteries are recycled to a large extent (see Part II).

**Oils and operating fluids**

The recovery of operating fluids (mainly engine oils, coolant, brake fluids, windscreen fluids, residual fuel) is a key element in ELV depollution and, then, it is an essential requirement for environmentally-sound dismantling. Non-appropriate fluids removal and dispersion in the environment can have significant impacts on dismantling sites contamination, while non-removal means the transmission of fluids to the shredding phase and then to landfilled ASR. The information on fluids actually removed from ELVs in the EU is highly incomplete in both

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\(^{16}\) The attempt to have an interview with representatives of the European association of producers (Eurobat) has been unsuccessful.
quantitative and qualitative terms, except for those operations occurring inside the industrial networks for ELVs where specific requirements and standards apply (see Part II). Some general figures exist about lubricant oil (not only from ELVs) suggesting that 57% is collected in EU countries and 60% of it is re-processed and refined for reuse. Various countries have specific regulatory framework for lubricant oil and some voluntary agreement for recovery. Even the introduction of stringent regulations on dismantling operations in recent years did not give rise to a more complete knowledge of practical behaviours on depollution from fluids.

Automobile Shredding Residue (ASR)

The estimated amount of ASR in the EU (2.2 million/tons) corresponds to less than 1% of total waste generated in the EU. The share is less than 0.3% of total in largest countries. According to the European Commission (1997) it represents 10% of total hazardous waste produced in the EU.

The classification of ASR is still subject to uncertainties (see Bontoux and Leone 1997). ASR is classified as hazardous by the Basel Convention on transboundary movements of waste and by EEC Regulation 259/93 (Amber list). At present, ASR is not considered as hazardous in the EC legislation. Although a procedure for including it in the European Hazardous Waste List is underway, the presently not-well defined legal status of ASR depends on the still evolving situation of EU waste legislation and, then, on a still limited possibility to translate new principles into practice in a clear-cut way (see Onida 1999 for a discussion). The different EU countries, therefore, classify and regulate ASR in different ways according to non-homogenous criteria (see IPEE 1996).

The composition of ASR can be highly variable according to the degree and type of treatment of ELV at dismantling and shredding phases. Table I.13 reports the composition of SR (thus including also residues from products different from automobile) as measured in Germany in 1998. Other data on composition emerged from various studies carried out by pilot experiments on recovery; they are different from those in the table but they share the same variability due to the specificity of the samples and the conditions of the input material.

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17 The attempt to have an interview with representatives of the European association of producers (UEIL) has been unsuccessful.
Table I.13.
**Estimated composition of ASR in Germany, 1998**

<table>
<thead>
<tr>
<th>Material</th>
<th>Share % or weight or mg per kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td>4-15</td>
</tr>
<tr>
<td>Plastics</td>
<td>25-35</td>
</tr>
<tr>
<td>Elastomers</td>
<td>5-30</td>
</tr>
<tr>
<td>Wood and textile</td>
<td>6-12</td>
</tr>
<tr>
<td>Road dirt</td>
<td>5-20</td>
</tr>
<tr>
<td>Operating fluids</td>
<td>6-7</td>
</tr>
<tr>
<td>PCB</td>
<td>0.05-0.20 mg/kg</td>
</tr>
<tr>
<td>PAK</td>
<td>18-45 mg/kg</td>
</tr>
</tbody>
</table>

Source: personal communications from Germany.

The presence of substances as PCB, which in other estimates is greater than in Table I.13, make the environmental impact of ASR a critical issue despite the not-too-large quantities landfilled. The possible recovery of ASR in the form of recycling of its constituent substances and in the form of energy recovery represents a large part of the debate about the technical solutions to the ELV problem. As we shall see (Part II and III), EU regulation is posing limitations to the maximum amount of ASR energy recovery under the priority of mechanical recycling whereas most of the industrial experiences and the positions of the involved industries give great significance to energy recovery. The latter is considered to represent a good solution to overcome the technical and economic limitation of post-user polymers recycling, thus helping in the continuation of the current trends in car material composition.

Plastics largely contribute to the relatively high calorific value of ASR-derived fuel (3,000 to 6,000 kcal/kg), and the same applies to the presence of elastomers - the latter suggesting a possibly non-complete removal of tyres from ELVs. The possible energy use of SR has been explored in the cement industry (France), in the pre-treatment of steel scrap (Italy), and in the substitution of heavy oil (Germany). The possibility of using ASR in hazardous-waste incineration facilities is also open but entails high costs for emission and ash treatment. The available data, in which ASR from cars is not recorded separately from SR from other durable goods, do not allow quantifying the exact amount of ASR used as fuel in Europe. The estimates made by IPEE (1996) based on individual operations suggest an amount of 12,000 tons in Belgium, 27,000 tons in France (including 3,500 tons of used tyres), 3,500 tons in Italy. These figures correspond to approximately 7.5% of ASR in France and 1% in Italy in 1996.

Another possibility is the recovery of materials from ASR. Some technologies are available and can reduce the amount and the toxicity of the residual landfilled to a great extent (see Part II and III).

The movements of ASR across EU countries are estimated to be negligible, also due to the inclusion of ASR among hazardous waste in the Basel Convention. The very different costs of ASR landfilling between different countries, however, can be a factor stimulating dismantling and shredding of ELVs in foreign countries, thus contributing of cross-border movements of ELVs (see Table I.14).
Table I.14
ASR landfilling costs in different countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Cost (US$ per tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EU countries</strong></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>140</td>
</tr>
<tr>
<td>Belgium</td>
<td>55</td>
</tr>
<tr>
<td>Denmark</td>
<td>70-110</td>
</tr>
<tr>
<td>France</td>
<td>40-60</td>
</tr>
<tr>
<td>Germany</td>
<td>60-170</td>
</tr>
<tr>
<td>Italy</td>
<td>75-80</td>
</tr>
<tr>
<td>Netherlands</td>
<td>70-90</td>
</tr>
<tr>
<td>Spain</td>
<td>20-60</td>
</tr>
<tr>
<td>Sweden</td>
<td>90-100</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>30-35</td>
</tr>
<tr>
<td><strong>Eastern European countries</strong></td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>25-30</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>30</td>
</tr>
<tr>
<td><strong>Non-EU countries</strong></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>20</td>
</tr>
<tr>
<td>Japan</td>
<td>135-160</td>
</tr>
<tr>
<td>Norway</td>
<td>50</td>
</tr>
<tr>
<td>United States</td>
<td>50-60</td>
</tr>
<tr>
<td>South Africa</td>
<td>25-40</td>
</tr>
<tr>
<td>Switzerland</td>
<td>120</td>
</tr>
</tbody>
</table>

Source: EUWIED, No. 21, November 26, 1999.

The trend in material composition of new cars (see above) represents a factor potentially leading to an increasing generation of ASR relative to the recovered/reused/recycled share of ELVs. Another trend making total ASR generation potentially increasing is the increasing average weight of European cars, although with the uncertainties discussed above. Finally, another factor pushing in the same direction is the ever-increasing number of car circulating in Europe. In a business-as-usual scenario, the combination of the three factors would make the absolute amount of ASR to increase. The combination of design innovations, increasing dismantling and recycling rates, and increasing ASR energy and/or material recovery, pursued by policies and industrial initiatives, can prevent form an increasing amount of ASR to be landfilled while decreasing its toxicity levels. Increasingly stringent regulations on waste landfilling in European countries push in the same direction.
I.2.3 Industrial actors and strategies

The industries involved in the ELV chain are very heterogeneous and can have differentiated interests in the process towards the solution of the issue. It is therefore appropriate to sketch the profile of the actors involved and their possible strategies.

Automobile industry

As illustrated in Par. I.1, the European car industry has an oligopolistic structure with few producers operating with scale economies in differentiated products at the international or global level. The trend emerging in Europe is a sort of “Germanisation” of the car industry because of the increasing role of Germany-based companies both in Europe and world-wide and the significant R&D investments on which this leadership is based. The increasingly oligopolistic feature and concentration of governance structure is accompanied by an increasing extent of “international production” and geographical dispersion of activities. These trends can be partly explained by the situation of over-capacity of the car industry at the world level. At the same time, they are induced by changes in car technology which brought about strong organisational adaptations during the 1980s and 1990s (see, among others, Bianchi 1989, Graves 1994, Wells and Rawlinson 1994). The integrated use of electronics, new materials and specific innovation in car design/making substantially improved car performance from the points of views of comfort, safety, energy consumption and pollution. One specific consequence of the changing material regime — from standardisation to a flexible regime in which the function dominate material innovation — has been an increasingly important role of the component industry, which partly become independent from major car companies and partly become the off-spring of the material producing industry. The car conception and design became increasingly interactive by involving component/material producers as well as external engineering services to a great extent (see Calabrese 1997 and 1999). Recently, Internet is increasingly considered as a source of major changes in the organisation of car production. On the one hand, the web can assume a significant role in the relationships between carmakers and input suppliers through real-time information and the development of e-commerce. On the other hand, it can be also a powerful instrument of reorganisation of car-selling networks by redefining the role of car dealers and allowing direct contacts with consumers also in the form of e-commerce. The approach to car assembling and car making in general could be influenced.

The possible significance of ELV for the car industry is mainly on car design and car making. Recycling and recyclability requirements can add one dimension to the interactive process of car conception and design so far dominated by the safety-comfort and energy-emission innovation trajectories. The latter enlarged the role of upstream industries and their innovations (materials and components) thus leading to increasing variety of solutions. The ELV problem, instead, can represent a constraint in the relationship between car producers and upstream industrial/innovation domains, possibly leading to a simplification process. The observed response of the car industry to ELV regulation is defensive in order to limit the possible adverse effects of recycling/recyclability constraints on car-design strategies driven by safety-comfort and energy-emission requirements. At the same time, however, the car industry response to ELV may contribute to redefine the control over the car production system, in particular at design and
component-production levels. The simplification of the material regime and the shifting of recycling/recyclability responsibility to components/materials industries (see Part II and III) seem to bring in this direction. The possible marketing dimension of ELV recycling, instead, seems to be limited, given the relatively low significance the consumer still attaches to recyclability. However, the solutions to ELV may be one component of more general environment-oriented strategies.

**Material producers and recyclers**

Material producers operate in the upstream part of the ELV chain, sometimes in connection with the component industry, while recycling industries are one of the terminal points of the downstream part of the chain. However, the recycling and material producing industries are vertically integrated in many sectors and, in some cases, they also have “vertically integrated strategies” on ELV.

**Metal industry.** Metal producers are generally large companies operating at the regional or global scale, although a great number of specialised producers exist in many countries. During the 1980s and 1990s, these companies undertook various strategic adaptations, including the propensity to become multi-material, under the pressures from low material prices, the “material revolution”, and the increasing environmental-policy sensitisiveness of materials (see Cohendet and Ledoux 1994). Although metals are considered to be “old materials”, in most cases they are highly innovative, as in the case of many steel alloys that can be considered as new advanced materials. The involvement of the different metal industries in the ELV issue is rather differentiated. On the one hand, some metal producers/recyclers (steel, aluminium) can benefit from developments in ELV management by increasing: (a) the possibility to have stable supply of raw materials, given the importance of ELV’s scraps for secondary productions, and (b) the opportunity to contrast the ascent of plastics in car material market on the basis of recyclability arguments. On the other hand, some metal producers (e.g. some non-ferrous metals) can suffer from provisions being introduced in ELV regulations regarding the limit values for some heavy metals in car making (see below and Part II and III). These problems obviously open innovation possibilities, but the latter are differentiated between the different metals and can result in a redistribution of material-market shares.

**Plastics industry.** Plastics producers are generally part of big companies of the chemical industry that, similarly to the car and metal industries, have been subject to extensive restructuring during the 1980s and 1990s as a consequence of technological innovation and strategic globalisation. Although plastic recycling is sometimes carried out by specialised companies in many countries, in other cases it is controlled by primary plastic producers. The plastic industry is one of the main actors of the above-mentioned reorganisation of car production both in terms of material regime and increasing role of component producers. An extensive development of plastic recycling from ELV is still constrained but, at the same time, plastic recycling is critical for solving the ELV waste problem without strong changes in material composition. Therefore, plastics producers and recyclers seems to consider ELV as a threat to their increasing control of key segments of the car-material market and efforts on plastic recyclability seems to be also aimed at the preservation of primary-plastics role in car
production. Significant R&D efforts, often in cooperation with the car industry, have been carried out on plastics’ recycling and ASR energy recovery (see Part II and III).

Other material industries. Other material industries (mainly glass, textile, rubber) seem to have a relatively passive attitude towards the ELV problem, although some companies might benefit from the increasing availability of materials to be recycled whereas other industries may suffer from the same developments (see Part II and III).

Dismantling industry

The European dismantling industry has a pivotal role in the ELV problem and it is already undertaking several changes under the pressure form ELV policy. Its exact profile in the EU is still rather difficult to define. Before the introduction of specific authorisation procedure in various countries (see Part II) the identification of dismantling companies was not free from difficulties. Some dismantling activities are carried out by companies working on car repair as the main business, some activities are in connection with metal scrap trade, and other activities are vertically integrated with the shredding industry. Table I.15 presents estimates on the number and features of dismantling industry in some European countries based on direct interviews.

In general, the industry is characterised by a great number of operators which, in many cases, are small and technically backward —as labour intensive operations prevails— and have a limited geographical scope. A significant amount of illegal dismantling operations still occurs in some countries, where the number of unauthorised dismantlers is still large (the so called “bad guys”). A core of efficient and well-organised dismantlers does exist, however, in all EU countries. Companies in the core are rapidly moving toward “professionalisation” and the introduction of techniques, technologies and standards that can comply with stringent regulations (Scharf 1999). Many dismantlers in various countries, especially those involved in the industrial voluntary agreements, are certified on ISO or other standards. The data in Table I.15 suggest that the most dynamic situation is in those countries where ELV regulation and VAs have been (or are being) implemented.
<table>
<thead>
<tr>
<th>Country</th>
<th>Estimated total number</th>
<th>Registered/authorised/certified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Belgium</td>
<td>450</td>
<td>50-60 certified; expected reduction of 50% of number after ELV legislation</td>
</tr>
<tr>
<td>Denmark</td>
<td>290</td>
<td>90 certified ISO; 100-150 not registered; expected 120-150 authorised under ELV legislation</td>
</tr>
<tr>
<td>France</td>
<td>2,000</td>
<td>&gt;1,000 uncontrolled; 900 valid permits; 423 certified (1999)</td>
</tr>
<tr>
<td>Finland</td>
<td>150</td>
<td>40-50 certified</td>
</tr>
<tr>
<td>Germany</td>
<td>4,000-5,000</td>
<td>1,100 already certified under ELV regulation (number rapidly increasing)</td>
</tr>
<tr>
<td>Greece</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Ireland</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Italy</td>
<td>4,500</td>
<td>1,500 authorised; certification expected after EU Directive</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Netherlands</td>
<td>907</td>
<td>907 licensed; 278 certified in ARN system</td>
</tr>
<tr>
<td>Portugal</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Spain</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Sweden</td>
<td>700</td>
<td>700 registered, 400 actually operating, expected 150 certified next future</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>3,500</td>
<td>2,000 licensed; 1,500 unlicensed</td>
</tr>
<tr>
<td>Total*</td>
<td>*17,000</td>
<td>7,307 authorised/registered/permitted/licensed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3,711 certified or being certified</td>
</tr>
</tbody>
</table>

* Only countries with direct information available.
Source: information from direct interviews and documents, and from Org-Consult.
The strategic interest of dismantling industry (the core) for ELV can be interpreted as the search for creating a new industry structure where only the best organised, efficient and regulation-complying operators can survive and enlarge their market share — although local-regional scale will remain. Although the future EU and national regulatory requirements on depolluting are now well-known, the delay in regulation introduction can prevent from doing the required investments (personal communications). Another uncertainty comes from the possible impact of EU Directive on the developments of industrial and national VAs to which dismantlers do participate (see Part III).

**Shredding industry**

The shredding industry performs the operations leading to metal/material recovery for recycling and the generation of ASR. In most European countries, the shredders are few large companies exploiting plant economies of scale, and some of them are also integrated with metal recyclers and producers but some of them are also integrated with dismantling activities. In the EU15 there are 222 shredding plants using magnetic separation for ferrous metals and 42 plants performing media separation, i.e. mechanical separation of non-magnetic shredder fraction to recover non-ferrous metals and stainless steel (Table I.16).

18 The attempt to have a direct interview with representatives of the European association of producers (EGARA) was unsuccessful. Some information is from ADA, the Italian association of dismantlers.

19 More recent data reported that for some countries the figure could be overestimated, Spain, for example, counts on only one large facility for media recovery and the rest of the plants are either small or dedicated to different residues (e.g. electric and electronic waste), Mr. Anton Askona, Ihobe S.A., Spain. Personal communication to IPTS-JRC, June 2000
The shredding and media separation industry in EU countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Shredders plants</th>
<th>Media separation plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Belgium</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Denmark</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>France</td>
<td>42</td>
<td>7</td>
</tr>
<tr>
<td>Finland</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Germany</td>
<td>54</td>
<td>8</td>
</tr>
<tr>
<td>Greece</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Ireland</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Italy</td>
<td>19</td>
<td>6</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Netherlands</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Portugal</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Spain</td>
<td>19</td>
<td>5</td>
</tr>
<tr>
<td>Sweden</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>42</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>222</strong></td>
<td><strong>42</strong></td>
</tr>
</tbody>
</table>


The significance of the ELV problem for the shredding industry depends on: (a) the possibility to increase and/or stabilise the flow of raw materials processed and delivered to metal (or material) recyclers; (b) to reduce the economic and environment-related costs of ASR through its cleaning and reduced amount, or through innovative economic outlets as energy and material recovery of ASR. ASR landfilling, in fact, is both an important cost item and a source of regulatory constraints. The strategy of maximising the “useful” material throughput of shredding while minimising waste residual is highly constrained by developments occurring in other parts of the ELV chain. Therefore, shredders are very active in various countries (e.g. France and Germany) in promoting ELV management networks in cooperation with dismantlers and the car industry (see Part II). The possibility to develop ASR energy (or material) recovery tends to enlarge the links between the shredding industry and other sectors, as the metal industry and the cement industry, and it is addressed by cooperative research and business efforts.
There is the possibility of a trade-off between different forms of recovery and recycling of metals along the ELV chain. If increasing dismantling for spare parts and reusable components involve increasing removal of metals before shredding, the quantities and the metals’ yield at shredding can be reduced. If, at the same time, there is not an increase in the removal of other materials at dismantling, in particular plastics and other non-metallic materials, there is a decreasing shredding yield and an increasing share of ASR compared to metals. The problem can be more significant with some non-ferrous metals as aluminium (personal communications).

Consumers

Although often disregarded in the debate, consumers are significant actors in ELV. Their attitudes about mobility and cars’ features are one of the key factors in car conception and design. They can decide about the timing of car renewal and, thus, can influence the average age (i.e. average features) of car stock and ELVs. They can also decide about the delivery to dismantlers (and to which dismantler) or the dispersion of their ELVs in the environment. Finally they are possibly the last payers of the incentive schemes being implemented for ELV (see Part III). It is true, however, that consumers have a little role in directly influencing key factors as the technical choices about material mix in car making, the behaviour of dismantlers, and the forms of ASR recovery/disposal. They have been under-represented in the development of ELV regulation in Europe due to technicality and complexity of the latter but also because of the low priority that consumers still seem to attach to recyclability in car buying decisions (personal communications).
I.3. NATIONAL POLICIES AND VOLUNTARY AGREEMENTS: OVERVIEW

During the last decade, the ELV problem was tackled by many initiatives belonging to different categories: company-level initiatives by carmakers, country-level voluntary agreements involving different industries, specific country-level legislation on ELV. Most of the initiatives were triggered by the process of EU-level regulation making, starting from the inclusion of ELV among the “Priority Waste Streams” by the European Commission in 1989 up to the EU Directive proposal of 1997 and subsequent developments. EU regulation development are presented in Par. I.4 below and a detailed analysis of the industrial and regulation developments in single countries is carried out in Part II. In this paragraph, a general picture of some features of the developments in European countries is presented in order to identify similarities and differences between countries — an important point for EU-level regulation. A summary of the situation for EU15 Member States (including the provisions of the Council Common Position 1999), Norway, United States, and Japan, is presented in Table I.17.

At end-1999, 10 EU Member countries (Austria, Belgium, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom) have specific regulations and/or industrial voluntary agreements addressing ELV. These countries represent a share of almost 96% of the “official” 8.8 million ELVs estimated in EU15. Other three countries are discussing industrial agreements (Finland and Ireland) or introducing legislation (Denmark). The only two countries still not developing initiatives are Greece and Luxembourg. Among the 10 countries with VAs, those having a piece of legislation directly addressing ELV are 6 (Austria, Belgium, Germany, Italy, the Netherlands, and Sweden). The introduction of ELV legislation in many countries, both having and not having VAs, is currently made dependent from the future introduction of EU Directive and its nation-level transposition. Austria, France, Italy, and the Netherlands introduced voluntary agreements or countrywide initiatives before 1995 (i.e. before the drafting of EU Directive proposal). The VAs and legislation in the other countries (Belgium, Germany, Portugal, Spain, Sweden) were developed in 1997-99 during the debate on the EU Directive proposal — but ELV was already a policy issue in Germany late-1980s and the same applies to Sweden (see Part II for details). All the policy schemes and VAs adopted specific targets for recovery/recycling of ELVs to be attained during the next fifteen years.

There are some degrees of convergence between the different national ELV policies and industrial initiatives but there are also substantial differences, especially regarding the combination between VAs and specific legislation and the policy instruments introduced.
### Table I.17

**ELV regulation and voluntary agreements in European countries, United States and Japan**

(information available at November 1999)

<table>
<thead>
<tr>
<th>Country</th>
<th>Specific regulation on ELV (entry into force)</th>
<th>Voluntary agreements</th>
<th>Certificate of destruction; depollution reg. or guidelines</th>
<th>Economic instruments/ incentives</th>
<th>Targets recovery/recycling (% of car weight)</th>
<th>Dismantlers in car-company networks</th>
<th>Design for dismantling/ design for recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>European Union</strong></td>
<td>Common Position July 1999 (after Directive proposal 1997 and Amended proposal June 1999)</td>
<td>Yes, possible at national level for the main provisions if they are enforceable, have specific objectives and deadlines, are monitored and results publicly available; in case of non-compliance Member States must implement by regulation, and legislation</td>
<td>Cert: yes, compulsory for deregistration Depol.: yes, compulsory specified in Annex I</td>
<td>Free take-back possible for ‘all or substantial part of costs’, conditional to integrity of car delivered; rules of implementation possibly defined at national level as a part of voluntary agreements; into force from 2001 for car on the market from 2001, from 2006 for cars on the market before 2001</td>
<td>85% reuse/recycling &lt;2006 with 80% recycling; for vehicle produced before 1980 lower targets possible with a limit of 75% reuse/recycling and 70% reuse/recycling 95% reuse/recycling &lt;2015 with 85% reuse/recycling; to be revised by 31.12.2005</td>
<td>—</td>
<td>Yes, must be promoted; dismantling manuals and information to be supplied by carmakers; dismantability, recoverability, recyclability standards to be established by 2001 to emend type-approval directive limits to the use of hazardous substances specified in Annex II; labelling of specific substances</td>
</tr>
<tr>
<td>France</td>
<td>Only general provisions from Law No. 1975/633 on waste disposal and material recovery</td>
<td>Accord Cadre (1993), 2 car companies, 8 professional associations, 2 ministries</td>
<td>Cert.: no Depol: yes</td>
<td>No (market conditions)</td>
<td>Voluntary: 85% recovery &gt; 2002, max. 200 kg waste 90% new car models &gt; 2002 95% “long run” (% recycling not specified)</td>
<td>Renault: 270 (86% of 312 certified); 260.000 ELVs treated in 1997* Great role of “managers-distributors” (shredding companies)</td>
<td>Renault: yes PSA: yes Co-operation in EUCAR</td>
</tr>
<tr>
<td>Germany</td>
<td>Allautoverordnung (April 1, 1998)</td>
<td>Voluntary pledge (1997), 15 professional associations</td>
<td>Cert.: yes Depol.: yes, reg. Apply also to exported ELV</td>
<td>Since 1998: free take back for car younger than 12 years; part of voluntary pledge</td>
<td>Statutory and voluntary: 85% recovery &gt; 2002 95% recovery &gt; 2015 (% recycling not specified)</td>
<td>Opel: 234 BMW: 90* Ford: 175 Various dismantlers contracted by shredders</td>
<td>All car makers on its own + joint efforts in PRAVDA Co-operation in EUCAR</td>
</tr>
<tr>
<td>Country</td>
<td>Specific regulation on ELV (entry into force)</td>
<td>Voluntary agreements</td>
<td>Certificate of destruction; depollution reg. or guidelines</td>
<td>Economic instruments/ incentives</td>
<td>Targets recovery/recycling (% of car weight)</td>
<td>Dismantlers in car company networks</td>
<td>Design for dismantling/ design for recycling</td>
</tr>
<tr>
<td>-------------</td>
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<td>----------------------------------------------------------</td>
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</tr>
<tr>
<td>Italy</td>
<td>Art. 46 of “Ronchi Decree” (1997); technical regulation in preparation</td>
<td>FIAT FARE system (1992); ‘Protocollo di intesa’ Ministry of Environment (1997)</td>
<td>Cert.: yes Depol.: yes</td>
<td>No (market mechanism)</td>
<td>Voluntary: 85% recovery &gt; 2002 95% recovery &gt; 2010 (% recycling not specified)</td>
<td>FIAT FARE: 312 in 1998 (25% of the total 1,500 authorised)*; 200,000 ELVs treated in 1997 and 800,000 in 1998 (scrap. scheme)</td>
<td>FIAT: yes Co-operation in EUCAR</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Dutch Environmental Management Act; disposal fee legally binding (1995)</td>
<td>ARN system (1993), 4 professional associations</td>
<td>Cert.: yes Depol.: yes</td>
<td>From 1995: disposal fee on new cars, recycling premium to dismantlers, recyclers and transporters contracted by ARN; financial fund managed by ARN</td>
<td>Voluntary: 86% recycling &gt; 2000 Energy recovery under consideration</td>
<td>ARN: 278 (30% of total licensed); 237,277 ELVs treated in 1997 (90% of total)</td>
<td>Under consideration</td>
</tr>
<tr>
<td>Sweden</td>
<td>Car scrapping legislation (1975); Ordinance on producer responsibility for vehicles (1.1.1998)</td>
<td>Proposed in 1994; 8 professional associations</td>
<td>Cert.: yes Depol.: yes, reg.</td>
<td>From 1975: scrapping fee on new cars, scrapping premium to last owner and dismantlers; financial fund (public); From 1998: free take back for new cars of own make registered after 1.1.1998</td>
<td>Statutory and voluntary 85% recovery &gt; 2002 95% recovery &gt; 2015 (% recycling not specified)</td>
<td>Volvo: 70 in 1999 (17.5% of 400 in activity)</td>
<td>Volvo: yes (ECRIS project) Saab: yes Co-operation in EUCAR</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Only ‘Duty of care’ regulation on delivery of waste vehicles to a licensed company (Environmental Protection Act 1990)</td>
<td>ACORD (1997); 7 professional associations; two Ministries involved</td>
<td>Cert: no Depol.: yes</td>
<td>No (market mechanism)</td>
<td>Voluntary: 85% recovery &gt; 2002 95% recovery &gt; 2015 (% recycling not specified)</td>
<td>—</td>
<td>Rover: yes Co-operative efforts in CARE project* Co-operation in EUCAR</td>
</tr>
<tr>
<td>Austria</td>
<td>1995 decree defining minimum requirements and standards</td>
<td>Signed September 1992; extended from 1996</td>
<td>Cert.: yes Depol.: yes</td>
<td>Free take-back for last-owner buying a new/used car</td>
<td>Voluntary: “recycling” 80% and, in the longer term, 95%; no deadlines indicated</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Country</td>
<td>Specific regulation on ELV (entry into force)</td>
<td>Voluntary agreements</td>
<td>Certificate of destruction; depollution reg. or guidelines</td>
<td>Economic instruments/ incentives</td>
<td>Targets recovery/recycling (% of car weight)</td>
<td>Dismantlers in car-company networks</td>
<td>Design for dismantling/design for recycling</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------</td>
<td>----------------------</td>
<td>-------------------------------------------------------------</td>
<td>--------------------------------</td>
<td>------------------------------------------</td>
<td>---------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Belgium</td>
<td>Flanders: approved December 1997; Brussels: Permit d’Environnement (June 1997); Vallonia: Plan Horizon 2010</td>
<td>Signed March 1999 national coverage; 8 professional associations and the environment ministries of the Regions</td>
<td>Cert.: yes Depol.: yes</td>
<td>Flanders and Brussels: from 1.1.1999; FTB for buyers of new cars; from 1.7.2004: FTB for old cars registered after 1.1.999; Vallonia: FTB under discussion</td>
<td>Statutory and voluntary (2005) for the three Regions: 85% recovery &lt;2005 with 80% recycling; 95% recovery &lt;2015 with 85% recycling</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Denmark</td>
<td>New legislation approved 1999 for entry into force expected 1.6.2000</td>
<td>No</td>
<td>Cert.: yes Depol.: yes</td>
<td>Recycling fee as annual additional tax collected by a fund; last-owner reimbursed in fixed amount for cost incurred in delivering to dismantlers</td>
<td>Not established</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Finland</td>
<td>Regulation on abandoned ELV; regulation in preparation similar to EU Directive; legislation on used tyres</td>
<td>No</td>
<td>Cert.: no Depol.: yes</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Greece</td>
<td>No specific regulation</td>
<td>No</td>
<td>Cert.: no Depol.: yes</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ireland</td>
<td>No specific regulation on ELV but under discussion; removal of batteries and oils under WMA 1996</td>
<td>Under discussion</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>No specific regulation</td>
<td>No</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Portugal</td>
<td>Expected</td>
<td>Signed June 1999; six professional associations</td>
<td>Cert.: yes Depol.: yes</td>
<td>No (market mechanism)</td>
<td>Voluntary: 85% recovery &gt; 2005 95% recovery &gt; 2015 (% recycling not specified)</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
### Regulation and Innovation in the area of End-of-Life Vehicles: ELV problem in Europe

<table>
<thead>
<tr>
<th>Country</th>
<th>Specific regulation on ELV (entry into force)</th>
<th>Voluntary agreements</th>
<th>Certificate of destruction; depollution reg. or guidelines</th>
<th>Economic instruments/incentives</th>
<th>Targets recovery/recycling (% of car weight)</th>
<th>Dismantlers in car-company networks</th>
<th>Design for dismantling/design for recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spain</td>
<td>No specific regulation but expected</td>
<td>Signed January 1996; 8 professional associations and two ministries</td>
<td>Cert: yes Depol: yes</td>
<td>No (market mechanism)</td>
<td>Voluntary: 85% recovery &gt; 2005 95% recovery &gt; 2015 (% recycling not specified)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Norway</td>
<td>No specific regulation</td>
<td>No</td>
<td>Cert.: no Depol.: yes</td>
<td>Scapping premium to last-owner (1,500 NOK) financed by import tax of 1,200 NOK delivered to a State-managed fund</td>
<td>No</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>United States</td>
<td>No specific regulation; waste laws apply</td>
<td>No</td>
<td>—</td>
<td>No (market mechanism)</td>
<td>No</td>
<td>Ford and GM initiatives for recovery/recycling loops with other industries</td>
<td>Cooperative initiatives (VRP, USAMP); Ford and GM industrial initiatives</td>
</tr>
<tr>
<td>Japan</td>
<td>No specific regulation; waste laws apply</td>
<td>Recycling Initiative on ELV 1997; 9 profes. associations and MITI; JAMA and single member companies Voluntary Action Plans</td>
<td>Cert.: na Depol.: yes</td>
<td>No (market mechanism)</td>
<td>Voluntary: 85% recovery &lt; 2002 with ASR landfilled at 3/5 of 1996 level 95% recovery &lt;2015 with ASR landfilled at 1/5 of 1996 level (% recycling not specified) Recyclability rate new vehicles: 90% &lt;2002; lead content in new vehicles: 50% of 1996 level by 2000; 33% of 1996 level by 2005</td>
<td>Various initiatives in Japan and currently in Europe</td>
<td>DFD and DFR research in individual companies and JAMA level</td>
</tr>
</tbody>
</table>

* BMW, FIAT, Renault, Rover and Volvo established an agreement that makes reciprocally available their dismantlers networks across European countries (see the text).

Source: country analyses of Part II; EEA (1997); Ford Europe (personal communications); IPTS-JRC (personal communications); Org-Consult (personal communications); Renault (1998); Council of the European Union (1999).
The most complex process of integration between industrial agreements and legislation occurred in Germany and Sweden, in both cases after a long confrontation between industry and environmental policy-makers based on opposite views about the distribution of responsibilities for solving the ELV problem. The car industry was the proponent of “shared responsibility” leading to the distribution of costs between all the industries involved, whereas policy makers were the proponent of “extended producer responsibility” leading to financial responsibility of the car industry in the attainment of higher ELV recovery/recycling rates. One specific point of contention was the introduction of economic incentive for downstream ELV operations based on free take-back (FTB) or similar instruments (see Part II and III for a detailed discussion). A similar confrontation occurred at the EU level (see below). In both the German and the Swedish cases, the result was a legislation including strong environmental and technical requirements for dismantling/shredding operations and the commitment by the car industry to apply FTB of ELV subject to specific conditions about the features (e.g. age) of ELVs. In both countries, individual carmakers are active in promoting recovery/recycling networks as well as R&D investments on design for recycling and dismantling. The actual use of FTB can be expected to be influenced by the coverage of networks and their contractual profiles (see Part II and III).

In other large countries as France, Italy and the United Kingdom, ELV policy is still largely based only on voluntary agreements promoted by the car industry and involving a number of other industries (including material producing industries). The features of these three national experiences also reflect the features of the “national” car industry, but all of them involved policy-making institutions to some extent. Both the French Accord Cadre and the English ACORD involved the Ministries of industry and environment as signatory parties, and, although there is not a national ELV agreement in Italy, the FARE system was included in the environmental agreement between FIAT and the Italian Ministry of the environment. One major feature of these VAs is the absence of specific economic instruments of the FTB-type and the prominence of free-market relationships between the actors in the agreements. The latter, are mainly based on contractual arrangements aimed at distributing the costs and advantages arising in ELV management, with the car industry assuming the role of coordinator. Apart from Italy, where a specific piece of waste legislation addresses ELV from 1998, the ELV-specific legislation framework is still incomplete in these countries, also because of the stand-by caused by the wait for the EU Directive.

Other countries with voluntary agreements present a mixed picture with regard to legislation and economic incentives. Austria combines the VA with a specific legislation and allows for a form of FTB by dealers in connection with new car sale. The recently signed agreement in Belgium (1999), now covering all the three regions after the autonomous initiative by Flanders, is backed by legislation and a form of FTB. In Portugal, an agreement was signed in 1999 which is not backed by specific legislation and does not include FTB (i.e. take back of ELV occurs at market conditions). The same applies to the Spanish agreement signed in 1996. The most recent voluntary agreements (Belgium, Portugal) as well as national policies under discussion (Denmark, Finland) are influenced by the expected contents of the EU Directive under discussion and try to anticipate them.

The agreement implemented in the Netherlands represents a specific approach to ELV policy. Its peculiarity consists in both the organisational framework and the economic incentive
Regulation and Innovation in the area of End-of-Life Vehicles: ELV problem in Europe

introduced (see Part II for details). The organisational framework is based on the integrated administration of the ELV treatment/recycling chain through a system of contacts between ARN, the independent company managing the agreement, and dismantlers and recyclers (but excluding shredders) aimed at reaching specific mechanical recycling targets. The economic instrument making the system work is a recycling fee levied on new car prices and redistributed by ARN to dismantlers and recyclers. The divergence between this system and the other voluntary agreements will be discussed in Part III. It must be mentioned that the regulatory framework for ELV in the Netherlands is not extensive but environmental requirements on dismantling/recycling are a part of the ARN system. Denmark is considering a scheme similar to the Dutch one, although with different distribution of funds from fees.

Voluntary agreements and/or national legislation have adopted similar recovery/recycling targets that are not-too distant from those of the EU Directive proposal 1997 and Common Position 1999 but differ in some important details. The reasons for the similarities will be discussed in Part II and III, while the differences between country-level targets (see Table I.17) can be highlighted in short.

Most of the countries established a total recovery rate of 85% of car weight by 2002 and a total recovery rate of 95% by 2015. One exception is France that did not establish a precise date for the 95% recovery rate (i.e. it is a long-term target). Another exception is the Netherlands, which established only the 86% recycling rate by 2000 while subordinating the 95% recovery (not recycling) by 2015 to the approval of EU Directive. Another exception is Austria that did not establish dates for the 80% and 95% recycling rates. With the exception of Austria, the Netherlands, and Belgium, most of the countries specify the targets only in terms of recovery rates and not in terms of recovery and recycling rates. This is, in general, a way for allowing the possibility of unconstrained energy recovery of ASR, differently from the EU Directive proposal 1997 and Common Position 1999 that establish (mechanical) recycling rates at specific dates in the future. Finally, in most countries the recovery targets remains voluntary in nature with no legislation forcing their achievement. Only in Germany, Sweden and, recently, Belgium, the targets are specified in the legislation and are both voluntary and statutory in nature.

The above situation might rapidly evolve after the approval of EU Directive, expected beginning-2000, and the possible directions of change will be discussed in Part III.

Initiatives on ELV in the other two major car-producing countries, i.e. the United States and Japan, are also evolving (see Part II for details).

In the United States, the attempt to introduce legislation on ELVs was not successful and only specific industrial initiatives are underway. The latter are mainly addressed to the recovery/recycling of useful parts and materials to be reintroduced in car making. Some of the developments in the United States were stimulated by the developments on ELV in the EU also with the expectation that recycling/recyclability requirements may represent barriers to market access.

In Japan, the developments are more similar to those occurring in the EU. Under the pressure from uncontrolled dismantling activities and scarce resource for landfilling, the recycling legislation of 1991 and the waste legislation of mid-1990s created more stringent requirements
for ELV operations. At the same time, the car manufacturers and other industries initiated an agreement to develop ELV management. The action plan is based on targets similar to those addressed by European VAs (85% recovery by 2002 and 95% recovery by 2015) and specific targets for the reduction of landfilled ASR. The general plan, managed by JAMA, the association of car manufacturers, is integrated by single carmakers’ plans. Recyclability targets for new cars have been established. The agreement does not include economic incentives.

I.4. DEVELOPMENTS OF EU REGULATION


Following the Commission’s “Community Strategy for Waste Management” of 1989, ELVs were included among the “priority waste streams” by a Council Resolution of 1990, that invited the Commission to define action programmes.

The difficulty to reconcile different positions immediately emerged, and the European “ELV Project Group” was established in 1991 by DG ENV, under the direction of the French ADEME, to explore the technical and policy options for the ELV issue. The Project Group included around 40 organisations and, among them, European car producers, plastics producers, steel and glass producers, car dismantlers and shredders, member-states’ representatives. The fact that Project Group represented all the interests involved in the ELV issues has been cast into doubt (see Onida 1999).

Despite the difficulty of reaching a consensus agreement, e.g. on specific recycling targets, the ELV Project Group worked until 1994 when produced a proposed strategy (ELV Project Group 1994). The agreed targets were: by 1995, drainage of fluids and cleaning from harmful substances of all collected ELVs; by 1998, collection, drainage and cleaning of all ELVs; by 2002, recycling of at least 85% of total car weight and recycling of at least 90% of the weight of new models; by 2015, 95% recycling in terms weight; preference of recycling over incineration. The “strategy” also included the priority to the preventive actions (design level). A wide range of regulatory measure, including at the Community level, was also proposed together with complementary actions.

In 1995, the Commission (DG ENV) began to draw a proposal that was discussed at various industrial and institutional levels. In November 1996, the Commission was asked by the European Parliament to produce a proposal on specific waste streams including ELV and to base it on the producer responsibility principle. The ELV Proposal, prepared by DG ENV and presented in 1997, took the form of a Directive proposal (European Commission 1997). It is partly based on the suggestions from the ELV Project Group as well as other studies and reports, e.g. the Task Force on “Car of Tomorrow” and the updates of the ELV Project Group made by IPEE in 1996. The preparation of the proposal encompassed an extensive consultation process in 1995-97 with more than 20 business organisations and other institutions. The Directive proposal, however, explicitly departed from the suggestions by the ELV Project Group by making specific regulation choices based on the view that ELV is mainly a waste-
management problem to be faced on the basis of financial “extended producer responsibility” principles\textsuperscript{20}.

The Proposal caused various adverse reactions by the industrial actors (see Par. 1.4.2), although with some differences among them. The debate and the controversial process of adoption went on during 1998 and 1999. The Directive has been based on Article 130s of the Treaty and, then, the legal procedure established in Article 189c (“co-operation procedure”). It is adopted by the Council in co-operation with the European Parliament. With the entry into force of the Amsterdam Treaty, which makes the procedures based on Article 100a and 130s very similar, the Directive will follow a “co-decision procedure” in which the powers of the Council and the Parliament are partly re-equilibrated, giving the Parliament more scope for influencing the content of the Directive (see Onida 1999 for a discussion).

After the consensus reached by the Council in December 1998 on the main Directive provisions, the Parliament made the first reading of the proposal in February 1999\textsuperscript{21}. A great number of amendments to the Directive were proposed. In March 1999, the Council decided to postpone the approval until June 1999 upon request by the German delegation. In June 1999 the Commission produced an amended proposal. In the Council session of June 1999, the difficulty of reaching a “common position” was still very clear. However, only one month later, in July 1999, the Council reached a “Common Position” that changes in some important points, e.g. voluntary agreements, the original Directive proposal of 1997 and the Amended proposal of 1999\textsuperscript{22}.

The main points of the 1997 Directive proposal (European Commission 1997), the amendments by the Parliament’s first reading (European Commission 1999a), the Amended proposal by the Commission (European Commission 1999b), and the “Common Position” of 1999 (Council of the European Union 1999) are summarised below\textsuperscript{23}.

\textit{Collection, authorised dismantling and destruction certificates (Art. 5).} The collection of ELVs up to 100\% should be achieved and the Member States should ensure that all ELVs are delivered to authorised treatment facilities. The collection/storage/dismantling facilities must be authorised and registered. The last owners will receive a certificate of destruction by the authorised facility, which is a condition for de-registration of the vehicle. Member States will ensure that mutual recognition applies to the certificates of destruction. The Parliament proposed to extend the provision on collection to the parts removed at car repair, and introduced the

\textsuperscript{20} The reasons behind the choice of a Directive, the main principles and the legal basis of the Directive proposal are discussed in details in Onida (1999).


\textsuperscript{22} The second reading by Parliament took place in February 2000, while this report was being completed. Most of the provisions contained in Common Position were not modified but the results from voting about the free take-back mechanism and its application to cars already in the market were unclear and requested the interpretation by legal expert of the Parliament. The latter concluded that the Parliament voted against the application of producer responsibility to cars already in the market, but the conclusion remains confused because of possible contradictions with other provisions of the Directive and it should be resolved by conciliation talks between the Council and the Parliament to be held during 2000.

\textsuperscript{23} The Directive applies to vehicles and end-of-life vehicles of category M1 and N1 as defined in Annex II (A) to Directive 70/156/EEC and two or three wheel vehicles; in the Common Position 1999 for two or three wheel vehicles only articles 5(1), 5(2), and 6 shall applies.
possibility to deliver ELV to the dealers/producers. According to the Common Position, dealers/producers may be permitted by Member States to issue certificates of destruction on behalf of an authorised treatment facility then transferring ELVs to the latter.

_Treatment and dismantling (Art 6)._ Storage and treatment facilities must comply with regulation on waste management and have to fulfil various requirements specified in the Annex I to the Directive (i.e. impermeabilisation, wastewater treatment, storage of fluids, collection of PCB/PCT, tyres, etc.). Material and components shall be removed and treated in selective way so that the shredder waste is not classified as hazardous waste. The vehicle must be stripped before treatment by removing all fluids, batteries, catalytic converters, air bags, tyres, and all hazardous components and materials. The Parliament proposed to enlarge the requirement of Article 6 and Annex I by requiring inspection on treatment facilities, by introducing more detailed requirements on the parts and components to be stripped, and by detailing the treatment operations to remove pollutants and promote recovery (e.g. removal of large plastic components, of metal components containing copper, aluminium and magnesium, etc.) up to the inclusion in Annex I of energy recovery of ASR. The Common Position 1999 simplified the requirements in Annex I, while retaining the most significant ones.

_Reuse/recycling/recovery targets (Art. 7)._ According to the Directive proposal 1997, by 1st January 2005 the recovery or reuse rate of all ELVs will have to achieve 85% in terms of weight and recycling or reuse 80%; by 1st January 2015 the reuse or recovery rate of all ELVs will have to be 95% of the weight and reuse or recycling 85%. The Parliament proposed that: for vehicles which received type-approval before 1st January 2005, the re-use/recovery shall be increased to a minimum of 85% of weight per vehicle and, from 2015, to a minimum of 95% (recycling not mentioned); for vehicles that received type approval after 1st January 2005 reuse/recovery shall increase to 95% of weight by 2015, while re-use/recycling shall increase to 85%. The Common Position 1999 maintains targets similar to those of the 1997 proposal but the date for the short-term targets (85% recovery and 80% recycling) is 1st January 2006 instead of 1st January 2005. In addition, provisions on re-examination of targets by 2005 and compliance control procedures about target attainment are introduced.

_Preference for mechanical recycling (Art 7)._ Although energy recovery from ELV waste is implicitly allowed in the 1997 proposal up to 5% of weight by 2005 and up to 10% of weight by 2015, material recycling is considered a priority “when environmentally viable, without prejudice to safety requirements”. Further to the above reformulation of targets on reuse/recycling/recovery rates, the Parliament proposed the additional requirement that this preference is “without prejudice to safety and environmental requirements of components, in particular those on exhaust gases and noise”.

_Recyclability, recoverability, reusability (Art 7 and 8)._ According to the 1997 proposal, specific amendments on type-approval regulation (Directive 70/156/EEC) as well as the promotion of specific European standards, will be introduced to ensure that vehicles approved after 1 January 2005 will be reusable/recyclable to a minimum of 85% and reusable/recoverable to a minimum of 95% of weight. The achievement of recoverability/reusability/recyclability is a responsibility of producers. The Parliament added the reference to the need that car producers initiate these developments immediately. Dismantling information and manuals (information)
should be provided to dismantling facilities and Member States should ensure that this apply by 31 December 1999. The Common Position 1999 maintained the key elements of recyclability provision of 1997 proposal but deleted the reference to responsibility of producers, defined end-2001 as the date for reaching agreed standards and established that the recyclability provision applies to car put on the market after three years after the amendments on type-approval Directive.

**Prevention, heavy metals and PVC (Art 4, Art. 6, and Recitals).** According to 1997 proposal, Member States shall ensure that lead, mercury, chromium, cadmium contained in vehicles put on the market after 1 January 2003 are prevented from being shredded, landfilled and incinerated. Components containing the same metals shall also be stripped before further treatment. The provisions on metals was amended by the Parliament by introducing a list of uses and limit-values for lead, mercury and hexavalent chromium in material and components for vehicles receiving type approval after 1 January 2005. More precise exclusions for landfilling of lead, cadmium and hexavalent chromium and shredding/landfilling/incineration for mercury were defined. The Common Position 1999 specifies in Annex II a list of uses and limit-values for lead, hexavalent chromium, and mercury to be used in materials and components of cars put on the market after 18 months after the entry into force of the Directive. It defines also a procedure for the amendment of Annex II according to technical and scientific progress in terms of "unavoidable/avoidable" criteria. Following the 1997 proposal, the environmental impacts of PVC in car waste (Recital 12) will be addressed by specific measures by the Commission. The Common Position 1999 states that the problem of PVC will be considered by proposals not specific to car as a product.

**Free-take back (Art 5 and Art 13).** In the 1997 proposal, free take-back of ELV is introduced by allowing the last owner of a car with limited recoverability/recyclability (negative market value), to be entitled to receive reimbursement by the car dealer/producer for the costs incurred in delivering to the authorised dismantler. The provision should apply from 1 January 2003. The provision was weakened by the Parliament by establishing that Member States shall ensure that "their respective collection systems do not give rise to any costs to the last holder and/or owner at delivery of the vehicle to an authorised treatment facility" when ELV have a negative market value and by deleting the provision on reimbursement by car dealer/producer. The original provision was substantially preserved in the amended Commission proposal. The Parliament proposed the requirement that the Commission produce every three years a report on any distortion on competition in the industries involved in ELV, from dealer to recyclers. The provision on entry into force in 2003 was deleted in both the Parliament amendments and the emended Commission proposal. The Parliament proposed the requirement that the Commission produce every three years a report on any distortion on competition in the industries involved in ELV, from dealer to recyclers. The formulation of FTB in Common Position 1999 is more flexible than the 1997 Proposal by establishing that "Member States shall take the necessary measures to ensure that producers meet all or a significant part of the cost of implementation of this measure and/or take back end-of-life vehicles" without any cost for the last owner. The provision (Art 5(4)) shall apply "as from 1st January 2001 for vehicles put on the market as from this date; as from 1st January 2006 for vehicles put on the market before the date referred to in the first indent".

**Voluntary agreements (Art. 10).** The 1997 Proposal did not consider (i.e. implicitly excluded) the possibility that the main provisions of the Directive are complied with by means of voluntary agreements.
agreements and mentioned only laws, regulations and administrative provisions. The Parliament introduced the possibility (in Art 11) that Member States develop voluntary agreements with economic operators to comply with article 5(1) on ELV collection. The Common Position 1999 introduces the possibility (Art. 10(3)) that Member States may transpose the provisions of various key articles by means of agreements between the competent authorities and the economic sectors concerned. The same applies to the detailed specifications of the free-take back mechanism. The agreements shall be enforceable, must specify objective and the corresponding dates, published in official journals, monitored regularly, and in case of non-compliance, Member States must implement the relevant provision of the Directive by legislation, regulation, and administrative measures.

I.4.2. Reactions by industrial actors

The three-year debate between the Commission and the industries involved by the ELV Directive cannot be analysed in detail. Some points of contention can emerge from the above-mentioned Parliament's amendments to the 1997 proposal and the articles' re-formulation in the Common Positions. Some of the positions expressed by industrial actors during the debate, and in particular on the 1997 proposal, are summarised below.

Carmakers\textsuperscript{24}

The ACEA (Association des Costructeurs Europeen d'Automobiles) published a position statement in May 1998 which opposes some key points of the Directive proposal (ACEA 1998). ACEA did not oppose ELV regulation in the form of a Directive. However, the introduction of destruction certificates and the certification of independent expert of dismantling/shredding activities was considered to be a sufficient regulatory framework for solving ELV-related environmental problems without impairing the initiatives by industries. In general, ACEA supported the validity of the approach taken by the ELV Project Group. The constraints on energy recovery of ASR disregarded appropriate development of thermal treatment in some countries and can impair the use of light materials (i.e. plastics) that can help in reaching greenhouse-emission objectives. The free-take back as formulated in the 1997 proposal was opposed. It was considered to create severe distortion to market operations while discouraging efficiency in car dismantling industry. It could also induce the car industry to take-over dismantling activities or could create very difficult monitoring problems. Carmakers raised (and still raise) strong opposition to the "retroactivity” of the FTB provision, given that it applies also to cars already in the market at the time of Directive introduction and not designed for recycling. The initial requirements on heavy metals’ exclusion were considered to go beyond current legislation and these metals were considered essential components of alloys supplying various environmental advantages through lightness. The limitation on VAs included in the Directive proposal 1997 was considered to impair the promising results being achieved by the voluntary initiatives in Member States. In general, ACEA claimed that the shared responsibility principle

\textsuperscript{24} Also based on personal communications from interview at ACEA, March 3, 1999.
Regulation and Innovation in the area of End-of-Life Vehicles: ELV problem in Europe

should apply to ELV. Even after the Common Position 1999, which is more favourable to industry's positions, ACEA declared (September 1999) to be considering legal actions against some Directive provisions as contrary to basic principles of European law. For FTB, in particular because of its "retroactivity", ACEA estimated a cost of 250-350 DM per vehicle and a total cost of 56 billion DM for carmakers.

Dismantlers

EGARA (European Group of Automotive Recycling Associations), which coordinates the initiatives of dismantlers (although not including all the national professional organisations), expressed a general approval on the Directive proposal, also in the light of the alleged weaknesses of voluntary agreements (see EGARA 1998, Scharff 1999). The dismantlers accepted the need for “professionalising” the dismantling industry through technical improvements reducing the environmental impacts of operations. The adoption of environmental standards should be the reference for the authorisation, licensing and certification of dismantlers. The increasing environmental and operational requirements, however, will greatly increase the dismantling costs that cannot be covered by the resale of parts and materials. The organisation was then favourable to free take-back provisions but would prefer a mechanisms similar to the Dutch one (recycling fees on new cars) to be extended in all the European countries. This was considered a way for reaching shared responsibility. To this end, the need to develop design for dismantling and design for recycling was stressed. A system of car-ownership taxes, to be released from when receiving a certificate of disposal, can create incentives to deliver to licensed dismantlers.

Metal producers and recyclers

Metal producing and recycling industries expressed various objections to the Directive proposal (see EFR 1998, Eurometaux 1998). Metal recyclers opposed free-take back. The economic problem of ELV was considered the high cost of recovery/treatment operation and the cost of ASR landfilling supported primarily by shredders. A system focused on the last-owner and dismantlers was considered useless for solving the problem because it increases costs and do not promote technological improvements. In a system focused on last-owner/dismantler, e.g. the Dutch system, shredders are excluded from incentives despite their costs for ASR disposal. The increasing removal of parts and components at dismantling involve parts with high non-ferrous metal content and leaves to shredders less metals and more plastics/non-metallic materials, thus subtracting valuable materials while increasing the relative amount of ASR. In general, metal recyclers feared the possibility that, as a reaction to free take back, the car industry could take a direct control of the dismantling industry. National voluntary agreements, instead, did not create adverse consequences. With reference to Directive targets, metal recyclers supported a

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26 Also based on personal communications from interviews to: BIR (Bureau International de la Recuperation), February 18, 1999; EEA (European Aluminium Association), February 17, 1999; EUROFER, March 3, 1999; EUROMEAUX, February 19, 1999.
balanced combination of material recycling/reuse and energy recovery by claiming that too ambitious recycling targets cannot be always justified on environmental and economic grounds. In general, because of the high development of metal recycling markets, ELV Directive raised the risk to distort the normal operation of the industry. ELV-related issues in the definition of metal residues as hazardous waste can create problems to the industry (see EFR, Eurometrec and BIR 1999). The provisions on heavy metals can create various problems. Lead is considered to be essential in alloys and metal processing and the amount of lead ending in landfill (i.e. not recovered by dismantling and shredding) is extremely low while the difficulties of substitution would be great in the short term. The attempts of substitution with bismuth, for example, are very expensive and can reduce the properties of metals alloys in processing/use.

**Plastic producers and recycler**

APME, the Association of Plastic Manufacturers in Europe, produced a position on ELV Directive proposal (APME 1997). It agreed that an EU-level regulation could be a supportive framework for voluntary initiatives but the formulation of the proposal could impair these initiatives. It is the first case of a waste directive on a complete product and it is mainly a “packaging-type” directive for a product that is very complex from the material composition point of view. The provisions on dismantling authorisation and destruction certificates are agreed. As for recycling targets, plastics should not be considered as hazardous and differentiation between old car and new car should be provided, given that cars becoming ELVs in 2005 are already on the road and are they not designed for recycling. The design of new cars aiming at recycling should not impair other environmental objectives pursued by current efforts on energy and emission efficiency which greatly depends on plastic. Life-cycle assessment, which is favourable to polymers, should prevail over dogmatic approaches. Almost 85% of energy consumption of a car occurs during its useful life and requirements on recyclability should not impair the achievement of energy/emission objectives. The recycling targets of the Directive are considered to be arbitrary. In some cases, energy recovery can be superior to mechanical recycling even on environmental grounds if a global approach is adopted. More flexible and pragmatic approaches, providing for more energy recovery and other technical solutions coming from innovation, should be adopted. Finally, although economic conditions for ELV varies from country to country, and in some cases temporary incentives should be needed, the free take back provisions are considered dangerous for the good working of economic relationships in the ELV chain.

27 Also based on information from a direct interview at APME, March 4, 1999.
1.4.3. Other policies relevant for ELV

Because of the variety and number of sectors, materials, and impacts involved in the ELV issue, various areas of environmental and industrial regulation can be significant for ELV. We can shortly consider waste regulation, climate policy, and air pollution policies.

Waste policy

The development of a specific regulation on ELV should be placed in the more general framework of waste policies that are relevant for ELV treatment. As suggested by the analysis in Par. I.2, ELV-related operations are subject to various pieces of EU and national regulation on waste (e.g. classifications, landfilling, incineration), regulations and agreements on recoverable parts/materials in cars (e.g. used tyres, batteries), and regulation on materials and substances considered as hazardous.\(^{28}\)

Climate change

EU actively participated to international climate change negotiations, in particular to the formulation of UNFCCC at UNCED in 1992. The post-Kyoto EU strategy was defined in 1998-1999 (see European Commission 1998a and 1999c) and it is still evolving. In accordance to Kyoto Protocol's provisions, the Commission is considering the so-called flexibility mechanisms (Joint Implementation, Clean Development Mechanism, Emission Trading). Despite their still imprecise technical definition, the latter involve to a large extent the use of market principles and the cooperation of economic actors.

The transport sector has a critical role in the post-Kyoto Commission's strategy. Greenhouse gases (GHG) emissions from transport are still increasing both in absolute amount and in relation to GDP. Significant improvements of GHG-emission efficiency from transport were achieved in the past. A European average car currently emits 171 grams of CO₂ per km compared to 175 grams of Japanese cars and 260 of American cars. However, unfavourable factors (e.g. stagnating emission-efficiency trends after the oil-price drop of 1986, an ever-increasing number of cars circulating in Europe, and the EU enlargement to transition countries) can boost emission growth in the next future. The Commission strategy of 1999 gives great emphasis on the agreements with the transport industry for achieving additional progress in GHG emission efficiency. After a long debate, the Commission (DG ENV) and ACEA reached an agreement in July 1998 for a commitment by ACEA based on quantified objectives of GHG emission reduction from new car models. The ACEA commitment with the Commission includes the introduction in the EU market by 2000 of individual models emitting 120 g/km of CO₂, the reduction of CO₂ emissions by 25%, down to 140 g/km, for all new cars by 2008, and a review in 2003 to evaluate the possibility to reach the objective of 120 g/km of CO₂ for all new cars by 2012 as requested by the Commission.

\(^{28}\) For a very comprehensive description of the legal framework of ELV see Onida (1999).
The ACEA commitments imply a priority for emission/energy efficiency in car design. The possibility that design and material-choice consequences of the ELV Directive can be in contrast with this priority is claimed by carmakers as well as other industries (personal communication). Even in the case that the emission targets are not-too-difficult to achieve, they have been formulated independently from the possible implications of recyclability requirements on design. Carmakers generally claim that emission targets are more important than ELV recycling and, if a trade-off should arise between recyclability and emission/energy efficiency, they will give priority to the latter (personal communications). On the side of policy making, the ELV Directive does not take into consideration the possible links with GHG emission policies, despite the institutional reference is the same for both the ELV Directive and the emission-efficiency agreement with ACEA. The separation of the two issues in environmental policy-making can be interpreted as the belief that the trade-off is not significant, or that car industry is technically and/or economically capable to solve the trade-off. The issue can be also viewed in the perspective of Integrated Product Policy on which future EU environmental regulation could be based (see Policy recommendation of this report).

**Air pollution policies**

The 1980s' EU-policies for phasing-out leaded gasoline have been implemented with different speeds in Member States. The Mediterranean States (e.g. Spain, Italy, Portugal and Greece) have been laggard in completing the phasing out and arrived at the deadline (December 31, 1999) with a large part of the car stock running with leaded gasoline. The decision of the Commission of December 1999 allows these States to have additional two years for comply with EU Directives (until end-December 2001). Although there are various technical solutions for running "old" cars without catalytic converters with unleaded gasoline, a wave of old cars' substitution is likely to take place in the "laggard" countries during the next few years. The consequences on ELV management in these countries can be very similar to those of car scrapping schemes of mid-1990s (see Par. 1.2). In particular, in Italy, despite the very different and uncertain estimates made by different institutions, an amount from 1 to 1.5 million cars (over a total of 18 million cars without catalytic converters) could be involved in the substitution process during the next two years. State incentives are under discussion or hypothesised, including a State contribution of about 100 Euros to have free dismantling of very old cars. Some carmakers selling in the Italian market have already launched incentives for the substitution of very old cars with new cars, and during the first months of 2000 old cars scrapped were about 300,000. Also the market of second-hand cars with catalytic converters is likely to be involved in the process.

By looking at the experience of scrapping schemes of 1990s, the short-term consequences could be that a great number of additional ELVs could arise during the first years of transposition/implementation of EU Directive on ELV. The management of a big flow of ELVs according to requirements of incoming EU and national regulations could be problematic, although concentrated in some (large) countries. At the same time, however, there could be positive scale effects that can favour the take-off of industrial networks for ELV dismantling.
and recycling/recovery/reuse. Longer-term effects can be in line with those discussed at Par. I.2.

An apparently distant policy addressing neither waste nor ELV, but a different environmental car-related problem, can influence to some extent the path towards ELV policy implementation.
PART II

ELV POLICIES IN SINGLE COUNTRIES
AND CARMAKERS' INITIATIVES

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II.1
II.1. France

New car registrations in France were 1,943,553 in 1998 (13.9% of total EU15). The registrations of new cars of French make (PSA and Renault) in EU15 were 3,177,390 in 1998 (22% of total EU15).

The estimated number of ELV from deregistrations was 1.8 million units in 1994 and the estimated amount of ASR from ELV was 360,000 tons in the same year (IPEE 1996). More recent estimates suggest that the total weight of ELVs in France was over 2 million tons in 1997 corresponding to over 2 million ELVs but under the effect of the Government's scrapping scheme.

II.1.1. ELV policy and management

The Accord Cadre

In 1991, ADEME (the French State Agency for Environment and Energy Conservation) took the responsibility in coordinating the European ELV Project Group established by the European Commission (see Part I). Also as a consequence of this responsibility, in 1993 the French government (the Ministries of the Environment and Industry), PSA Peugeot Citroen, Renault SA, and eight professional associations involved in ELV agreed on the Accord Cadre, the first national voluntary agreement in Europe pursuing a self-regulation of ELV management (Ministere de l'Environment et al 1993).  

The Accord Cadre included the objective to channel all scrap vehicles in the reprocessing chain by 2002, together with the specific targets to reduce ELV final waste to a maximum level of 15% of the car weight by 2002 with a ceiling of 200 kg, a maximum ASR level of 10% for new models produced from 2002, and a maximum level of 5% of total weight in the long term (year not specified).

To reach the objectives, the Accord Cadre included a series of commitments by the different industrial categories involved.

29 The analysis is also based on the interviews with Jean Paul Vallat (Renault) and Pierre Picot (IXAS Conseil) and the written communications by Pascal Feillard (PSA Peugeot Citroen). For details on the situation before 1996, see also Den Hond (1996), IPEE (1996), Aggeri and Hatchuel (1997). A detailed analysis of the French agreement up to mid-1990s has been produced by EEA (1997).

30 The participants to the Accord Cadre, signed in March 1993, are the Ministry of Environment, the Ministry of Industry and Foreign Trade, PSA-Peugeot-Citroen, Régie Nationale des Usines Renault SA, the branch Démolisseurs d'Automobiles of the Conseil National des Professions de l'Automobile, Fédération Française de la Récupération pour la Gestion Industrielle de l'Environnement et du Recyclage (FEDEREC), Commission de Broyeurs of FEDEREC, Fédération Française de l'Acier, Fédération des Mineurs, Minéraux Industriels et Métaux non ferreux, Syndicat des Producteurs de Matières Plastiques, Fédération des Industries des Equipements pour Véhicules, Fédération de Plasturgie.
The car and equipment manufacturers committed:

- to intensify R&D efforts in connection with suppliers and the public authorities to produce and use parts with higher degree of reprocessing possibilities;
- to use increasing amounts of recycled materials “within the scope of existing technologies”;
- to adapt design consequently with the constraints imposed by other functional requirements;
- to ensure that by the year 2002, new models may be reprocessed to generate a final waste not exceeding 10% of the total weight under the condition of economic feasibility and sufficient degree of innovation taking place;
- to provide information and introduce marking of parts to enable dismantling and recycling, to supply technical assistance and develop cooperation also at the European level.

The dismantlers and recyclers committed:

- to comply with the responsibility of reprocessing of vehicles also in agreements with other downstream operators;
- to take in charge the vehicle from the last owner with full information on the transfer of ownership and at the prevailing market conditions within the competition rules;
- to take into account the technical information from manufacturers and to intensify their efforts for technical and economic efficiency of their operations;
- to supply information on the state of reprocessing activities.

The material manufacturers committed:

- to develop their relations with manufacturers and dismantlers/recyclers for allowing optimisation of material choice for environmental protection;
- to intensify R&D on material revalorization, to develop recycling channels to increase reprocessing of metals;
- to participate to industrial initiatives aimed at developing revalorization of synthetic materials.

The public authorities, by accepting that the above commitments are suitable to ensure the objective achievement and the protection of the environment, committed:

- to enforcing the campaign against unauthorised dumping of ELV;
- to control the compliance on existing regulation by the reprocessing operators;
- to take statutory measures if required and in accordance with the framework agreement.

At the European level, all the parties committed to reduce the scrap from ELV in accordance to proximity principles, check that competitive conditions are maintained, and prevent national regulation from becoming a restriction on trade of new vehicles.
Further to the adoption of free market principles, the Accord Cadre did not pose limitations to the choice among different technologies and technical approaches, including energy recovery.

The manager-distributors system and its organisation

Also as a consequence of the Accord Cadre, a pivotal role in the French system for ELV has been taken by the so-called “manager-distributors” (MD). They are in general subsidiaries of the shredder or dismantling companies that work out a complex systems of contractual agreement with the actors of the ELV chain (see Den Hond 1996, Renault 1998). They buy the ELVs from the selling network of carmakers and importers (i.e. dealers to which ELVs are often delivered by last owner) and re-sell them to a network of dismantlers that meet specifications defined by carmakers. The MD thus supply the car makers a set of services: management of removal of ELVs from the dealer network; follow-up management at the dismantlers and shredder level; organisation of industrial units for pre-shredding processing; monitoring and reporting on the status of operations. They perform also the role of distributors of recyclable materials to other industries involved in ELV recycling. The organisation and their relationship with car makers is illustrated in Table II.1.1

The contractual agreement between MD, carmakers and dismantlers are based on general framework agreements while the specific agreements between shredders and dismantlers are bilateral. The conditions are freely established but are also suggested by the car company involved and there is full information between the different partners in order to favour transparent behaviours (personal communications). Given the MD ownership structure, however, shredders have a great role in the whole system and act as intermediaries in the different phase of post-consumer operations of the ELV chain on behalf of carmakers. The system, however, does not cover all the ELV activities taking place in France.

The estimated number of companies storing and dismantling ELV in France was 2,000 in 1998. More than 1,000 are considered still uncontrolled sites, while about 900 had valid operating permits. The dismantlers are represented by a specific branch of the National Automotive Council (Conseil National des Profession de l’Automobile - CNPA) that has 500 members and initiated a certification process in 1994. The certification address the environmental management of dismantling (removing of battery, fuels, operating fluids, air gabs, pretensioners, LPG tanks), neutralisation of airbags, physical and administrative traceability of ELV during the treatment period, commitment to take back the ELV at the market price, and other requirements on information of customers and training of personnel. In August 1999, 493 dismantlers of the CNPA were certified and the expected number was 500 by end-1999 (personal communications). CNPA is now undertaking actions to establish control systems for uncontrolled sites that, further to environmental damages, can create also competitive displacement of certified dismantlers.
Table II.1.1. The organisation of manager-distributors in France, 1998

<table>
<thead>
<tr>
<th>Companies (shareholders)</th>
<th>Car maker/importer customer and activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valorauto (100% Galloo shredder group)</td>
<td>Renault (Northern France)</td>
</tr>
<tr>
<td></td>
<td>Opel (Northern-Eastern France and Normandy)</td>
</tr>
<tr>
<td>ORA (50% CFF and 50% Dauphin)</td>
<td>Renault (Normandy and Brittany)</td>
</tr>
<tr>
<td>ECO-VHU (100% CFF)</td>
<td>Renault (approx. 75% of all ELVs)</td>
</tr>
<tr>
<td></td>
<td>PSA (Rhone-Alpes region)</td>
</tr>
<tr>
<td></td>
<td>FIAT</td>
</tr>
<tr>
<td></td>
<td>BMW</td>
</tr>
<tr>
<td></td>
<td>Mercedes</td>
</tr>
<tr>
<td></td>
<td>Rover</td>
</tr>
<tr>
<td></td>
<td>Opel</td>
</tr>
<tr>
<td></td>
<td>VAG</td>
</tr>
<tr>
<td></td>
<td>Nissan</td>
</tr>
<tr>
<td></td>
<td>Honda</td>
</tr>
<tr>
<td></td>
<td>Volvo (planned in 1998)</td>
</tr>
<tr>
<td>INDRA (independent, with stakes in various</td>
<td>PSA (except Rhône-Alpes region)</td>
</tr>
<tr>
<td>dismantlers)</td>
<td>Ford</td>
</tr>
</tbody>
</table>

Source: adapted from Renault (1998).

The shredders in activity in 1998 were 45 and almost half of them were part of the Compagnie Francaise des Ferrailles (CFF) group. A certain amount of ASR is recovered (about 28,000 tons in 1997) mostly for the production of a feedstock for the cement industry. In particular, one shredder of CFF (St Pierre de Chandieu) recovers a mixture of SR and tyres in a Vicat cement plant (11,000 tons in 1997); one shredder of Galloo France (Halluin) recovers SR for the cement plant CBR in Antoing (Belgium) (15,000 tons); Lormet (Pagny sur Meuse) recover SR for four cement plants of Origny (2,000 tons). There are some transfrontier movements of ELV operated by dismantlers with Southern Europe (Italy and Spain) (personal communications).

Tyres from ELV are mainly used in the cement industry and are shredded before use. The ten glass recyclers operating with ELV materials provide a service with uniform reclaiming prices from zero to 125 FF per ton delivered on a uniform countrywide basis. One industrial unit working since 1996 treated about 86 tons of glass in 1997. Two companies are currently operating on plastic recycling from cars (mainly bumpers). The first one, C2P, works with PP bumpers for cascade recycling. The second one, MECELEC, works with SMC bumper to make road substrates.

According to the provisions of the Accord Cadre, there are monitoring activities of the progress made based on a specific committee (ISAC - Instance de Suivi de l’Accord Cadre). Three main indicators have been or are being developed. The first one is an indicator on ELV collection managed by ADEME; the second one is an indicator on the rate of recovery and will be elaborated regularly on the basis of “shredding campaigns”; the third indicator is that on “vehicle recyclability rate” (ICI - Indicator Conception ISAC) which is developed by Renault and is being validated by Renault and PSA jointly.
In general, the Accord Cadre is considered to have had a significant impact on the organisation of various aspects of ELV (personal communications, Renault 1998, PSA 1999).

Among the achievements are considered: the spreading of certification of dismantling activities and some results on recovery of ASR; the development of monitoring body as a part of Accord Cadre development; the research investments by material producers as Valcor and Autovynil; the developments in DFD and DFR which will be analysed below. However, some major obstacles still prevent from the achievement of the objectives for all ELVs: the lack of financial incentives for the last owner to direct her/his ELV towards certified structures for dismantling; the still lacking coordination of the recycling chain for materials other than metals; the still negative economic balances of certain recycling operations.

In general, the developments in the ELV recycling activities are at different stage of development. The dismantlers’ certification and ASR recovery in the cement industry are already at operational level. The recovery of shredding residues in fluidised furnace, instead, is waiting for operating permits. The recovery of plastics from SR is still under testing. The recovery of glass and materials for road construction form SR are under study. A negative economic balance still prevent the development of collection of glass and bumpers from dismantlers and, with large negative results, the collection of seat foams and other plastic parts from dismantlers (see Renault 1998, personal communications).

Renault and PSA are proposing to establish a neutral national coordinating structure acting on behalf of the Monitoring Body of the Accord Cadre to address the above shortcomings with the aim of:

- to implement the ISAC system;
- to coordinate the development of recycling, taking into account that ASR recycling activities are close to the break-even point;
- to provide, if necessary, “financial management” of the loss-making structures; to develop the indicators and information systems.

The coordinating structure can be financed by signatories of the Accord Cadre (see Renault 1998).

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31 Differently from those countries, e.g. Germany and Italy, where property taxes and responsibilities for non-deregistered vehicles create the incentive to deregister.
II.1.2. Industrial experiences

II.1.2.1. Renault SA

Starting early 1990s, Renault developed a comprehensive approach to ELV based on the concept of “zéro déchets en décharge”. It includes the development of a logistic system for ELV and spare-parts, the development of recycling and energy recovery technologies, the improvement of future recyclability, the creation of economic values at each stage of ELV processing. Great attention was devoted during the 1990s to the research on plastic recyclability and Renault engaged in various projects with Dow Chemical, Atochem, CPP, and Rhone Poulenc addressing different plastic materials (ABS, PP, PA). The Renault strategy in 1992-95 was based the creation of dismantling pilot experiences and the participation to “Major Innovative Projects” in 1992-97 (see below).

From mid-1990s, Renault decided to exploit the coordination advantages offered by the MD system to pursue the commitments of the Accord Cadre. The 1998-99 contracts include various commitments by dismantlers and shredders. The dismantlers working with Renault have to comply with the environmental and labour regulations in force, as well as with the certification requirements (Qualicert or ISO) about ELV depolluting. Furthermore:

- they must participate in pre-shredding industrial units managed by contracted MD;
- they have to assure the traceability of ELVs and materials in their operations;
- they must sell the wrecks to one of the shredders having an agreement with the MD;
- they must comply with other information and procedural requirements.

The shredders have similar obligations and, more specifically, the obligation to sell ASR to operators complying with the relevant regulations in force. Both dismantlers and shredders have to fulfil obligations about reporting to MD that is responsible for reporting to the carmaker. Renault supplies various technical support and information activities.

The dismantlers contracted by Renault in 1997 were 270 and processed 260,000 ELVs (Table II.1.2). Out of the total ELVs, 76,000 came from the MD system and 184,000 from insurance companies, private owners, public bodies and garages. The sudden drop compared to the 460,000 ELVs processed in 1996 is due to the termination of the French incentive scheme for scrapping old cars. The calculations on the rate of treatment are based on an average car weight of 870 kg and the results on “status panels” on removal of fluids parts. The weight of wrecks delivered to shredders is calculated at 684 kg per car (78.6% of the initial weight).

32 The analysis is also based on the interview with Jean Paul Vallat (Renault SA) and other communications by Renault SA.
Table II.1.2
Activities of the dismantlers contacted by Renault and quantity of material treated

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of dismantlers</td>
<td>280</td>
<td>270*</td>
<td>255</td>
</tr>
<tr>
<td>Number of ELVs treated</td>
<td>460,000</td>
<td>260,000**</td>
<td>268,000</td>
</tr>
<tr>
<td>ELV tons to be shredded</td>
<td>na</td>
<td>160,000</td>
<td>115,000</td>
</tr>
<tr>
<td>Batteries recovered</td>
<td>5,100 tons</td>
<td>3,600 tons</td>
<td>2,300 tons</td>
</tr>
<tr>
<td>Oil and brake fluids recovered</td>
<td>1.8 million/litres</td>
<td>1.3 million/litres</td>
<td>1.1 million/litres</td>
</tr>
<tr>
<td>Coolant and windscreen washer fluids</td>
<td>0.41 million/litres</td>
<td>0.43 million/litres</td>
<td>0.44 million/litres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rate of treatment per average car (870 kg)</th>
<th>Percent</th>
<th>Weight (kg)</th>
<th>Weight (kg) (new convention)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>4.4</td>
<td>38</td>
<td>7</td>
</tr>
<tr>
<td>Batteries</td>
<td>1.6</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Oils and brake fluids</td>
<td>0.6</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Coolant and windscreen washer</td>
<td>0.2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Second hand parts</td>
<td>14.6</td>
<td>127</td>
<td>131</td>
</tr>
<tr>
<td>Overall rate for dismantlers</td>
<td>21.4</td>
<td>186</td>
<td>155</td>
</tr>
</tbody>
</table>

* 214 with ECO-VHU and ORA, and 56 with Valorauto.
** Of which 100,000 of Renault make.
Source: Renault (1998) and personal communications.

Table II.1.3.
The activities of shredders associated with Renault, 1997 and 1998
(tons and percentage)

<table>
<thead>
<tr>
<th>Activities</th>
<th>1997</th>
<th>Rate of treatment</th>
<th>1998</th>
<th>Rate of treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of shredders reporting (status panel)</td>
<td>32*</td>
<td>-</td>
<td>32*</td>
<td>-</td>
</tr>
<tr>
<td>Weight of ELVs input from dismantlers under contract</td>
<td>136,000</td>
<td>-</td>
<td>92,000</td>
<td>-</td>
</tr>
<tr>
<td>Weight of ELVs from other sources</td>
<td>660,000</td>
<td>-</td>
<td>518,000</td>
<td>-</td>
</tr>
<tr>
<td>Other supplies</td>
<td>1,273,000</td>
<td>-</td>
<td>1,181,000</td>
<td>-</td>
</tr>
<tr>
<td>Total input</td>
<td>2,069,000</td>
<td>-</td>
<td>1,793,000</td>
<td>-</td>
</tr>
<tr>
<td>Ratio of ELVs to total shredded</td>
<td>38%</td>
<td>34%</td>
<td>38%</td>
<td>34%</td>
</tr>
<tr>
<td>Ferrous and non-ferrous metals recovered</td>
<td>1,557,000</td>
<td>77.8%</td>
<td>1,381,000</td>
<td>77.6%</td>
</tr>
<tr>
<td>Shredding residue recovered</td>
<td>28,000</td>
<td>1.4%</td>
<td>30,800</td>
<td>1.7%</td>
</tr>
<tr>
<td>Shredding residue in landfill dumps</td>
<td>416,000</td>
<td>20.8%</td>
<td>368,000</td>
<td>20.7%</td>
</tr>
<tr>
<td>Total output</td>
<td>2,001,000</td>
<td>100%</td>
<td>1,780,000</td>
<td>10%</td>
</tr>
</tbody>
</table>

* 25 with ECON-VHU and ORA, and 7 with Valorauto.
Source: adapted from Renault (1998) and personal communications.

From the shredders reporting their activities though the “status panel”, the data in Table II.1.3 emerges for 1997 (the first year for which the status panel of shredders is available).
By assuming that the total rates of treatment can be applied to all ELVs, it is calculated that the total weight recovered by shredders (metals and recovered ASR) amounts to 587 kg per ELV or 65.6% of initial weight (895 kg with 7 kg of fuel, i.e. 10 litres). By adding it to the weight recovered by dismantlers an average reuse/recovery/recycling of 82.9% in the Renault system is calculated (Table II.1.4) which is not-too far from the 2002 targets and does not include energy recovery of ASR (see also Joly 1999).

Table II.1.4.
Rate of recovery in the Renault system, 1998

<table>
<thead>
<tr>
<th>Activity</th>
<th>Weight (kg)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery by dismantlers</td>
<td>155</td>
<td>17.3%</td>
</tr>
<tr>
<td>Recovery by shredders (metals + recovered ASR)</td>
<td>587</td>
<td>65.6%</td>
</tr>
<tr>
<td>Total recovered</td>
<td>742</td>
<td>82.9%</td>
</tr>
<tr>
<td>Placed in landfill dumps</td>
<td>153</td>
<td>17.3%</td>
</tr>
<tr>
<td>Total (initial car weight)*</td>
<td>895</td>
<td>100%</td>
</tr>
</tbody>
</table>

* Including 10 litres of fuel.
Source: personal communications by Renault.

The role of Renault is very significant in the actual working of the MD system. Renault is very selective in choosing dismantlers and submits them under severe controls while helping them to find possible markets for recyclable materials. The dismantlers in the network are gaining the advantages of sure supply of ELVs to process and are gaining market shares at the expenses of dismantlers outside the network (personal communications). On the other hand, Renault is developing innovative relationships with shredders, material recyclers and suppliers. The system should be based on the objective of stabilising the markets for raw materials. Standard prices for materials are being defined through technical coefficients of use in industrial processing. The possible development of a closed loop for materials in which the material suppliers are paid for the “service” offered by the material which remain of the supplier is being envisaged. The partners in the definition of the system are CFF and Teksid (personal communications).

Renault signed a partnership agreements with BMW (1994), FIAT (1994), Rover (1995) and Volvo (1998) for the treatment of ELVs in the different European countries. Each car maker has agreed to organise the ELV treatment also on behalf of its partners in specified countries using its own contractual network (Table II.1.5). Under the system, the importing subsidiaries of BMW, FIAT and Rover have signed contracts with ECO-VHU in accordance with the terms defined by Renault and Volvo was expected to sign same commitment in 1998.
Table II.1.5.
Scope of the agreement between Renault, BMW, FIAT, Rover and Volvo*

<table>
<thead>
<tr>
<th>Date of agreement</th>
<th>Partner</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>Renault</td>
<td>France, Spain, Portugal, Belgium</td>
</tr>
<tr>
<td>1994</td>
<td>BMW</td>
<td>Germany, Austria, Switzerland, the Netherlands</td>
</tr>
<tr>
<td>1994</td>
<td>FIAT</td>
<td>Italy, Greece</td>
</tr>
<tr>
<td>1995</td>
<td>Rover</td>
<td>United Kingdom, Ireland</td>
</tr>
<tr>
<td>1998</td>
<td>Volvo</td>
<td>Sweden, Norway, Finland, Denmark</td>
</tr>
</tbody>
</table>

* The initial contract is currently (September 1999) under discussion and should be slightly modified. Source: Renault (1998) and personal communications.

Renault organised with CAT (Compagnie d’Affètment at de Transport) a circuit for the collection of car products (end-of-life products - ELPs) deriving from repair and maintenance activities at the dealers and garage workshops. In 1997, the system collected, among other ELPs, 61,500 tyres, 96,800 bumpers, 85,700 batteries. In 1997, an agreement for collection of reuse/recycling of ELPs was signed with PLAOREC (non-hazardous materials) and CHIMIREC (hazardous materials).

In 1995, Renault began to develop guidelines for DFD/DFR. On the practical side, an objective of 86% recyclability was established for Clio II. In the fields of DFD, some of the guidelines are about wiring of the pyrotechnic elements, the procedures and tools for the drainage of fluids, accessibility of fasteners. In the field of DFR, some guidelines are about recyclability constraints on plastic parts, the reduction of chlorine content (from 3.5% to 1.0% in ASR) by using polyethylene, the exclusion of lead from some components. These procedures, successfully applied to Clio II, are now applied to all vehicle projects.

The material substitution processes seem to be, in general, rather prudent. Instead of reducing the number of polymers, for example, it is preferred to reduce the number of polymers in the same component. It is expected, however, that due to reasons different from recyclability, the car of the future will contain a different combination of materials, e.g. a greater amount of glass, up to 60 kg (personal communications).

Measurement tools, as recyclability indicators and LCA, are used to support DFD and DFR. For recyclability coefficients, Renault developed its own indicators in cooperation with PSA and the component producers under the Accord Cadre and participates to the attempts of harmonisation at the European level under EuCar-ACEA initiative. In this framework, cooperation is developing with Daimler-Benz and GM-Opel as well as with American and Japanese carmakers.

LCA is performed to make comparative evaluations of the environmental profile of different components/materials and it is used in particular for placing the ELV phase in the whole life cycle. A case of LCA is that developed for PE-HD fuel tanks.

It is in the view of Renault that the possible trade-off between recyclability and emission saving is indeed problematic but it can be solved through research efforts at various level. It might be
possible to have a 90% recyclable car without giving up light materials, although constraints emerge on economic grounds (personal communications).

In general, the process of DFD and DFR development is depicted as highly interactive between the different expertise involved inside and outside the company. It is managed by stating objective and then by open discussions on the possible solution without dogmatic approach and maintain different options open to avoid the loss of innovation possibilities (personal communications).

Renault participated with other industrial partners to three Major Innovative Projects (MIPs) concluded in 1997 (Table II.1.6).

Table II.1.6.
“Major Innovative Projects”

<table>
<thead>
<tr>
<th>Topic</th>
<th>Partners</th>
<th>Duration</th>
<th>Cost</th>
<th>Aids</th>
</tr>
</thead>
<tbody>
<tr>
<td>automotive plastics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycling of</td>
<td>Renault, French Ministry of Industry, Cray Valley, ECIA, Inoplast, Maec, Matra, Meceled Composites, Menzolit, PSA, Valeo</td>
<td>1993-1997</td>
<td>56.5 mil. FF</td>
<td>Subsidy 29.54%</td>
</tr>
<tr>
<td>SMC/BMC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>from SR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Among the results of the MIP on plastic recycling are the development of PP recycled bumpers for some Renault models, the use of recycled PP on wheel of 100% of the Renault range, and the use of the same material for other standard parts; the recycling of shock absorbers at the industrial scale and the use of recycled polyethylene for the shock absorbers of Laguna since 1995. The consumption of recycled plastics at Renault reached 5,000 tons in 1997. As a result of MIP on SMC/BMC recycling, the certification of SMC/BMC parts containing 5%-15% of recycled material was obtained. Finally, the MIP on energy recovery of SR lead to the development of shredding residue treatment lines at Galloo-France and Charleroi, and the line for introduction of solid fuels in a cement plant (see Renault 1998).
II.1.2.2. PSA - Peugeot Citroën

PSA Peugeot Citroën established its commitment to recycling and the management of ELVs by signing the French framework agreement of March 1993.

The Group's strategy has three main areas of focus:

- to recycle cars in accordance with regulatory requirements, going beyond requirements where economically viable;
- to develop the re-use of parts;
- to limit the waste generated by vehicle maintenance.

The first part of the Group's strategy consists in designing and manufacturing vehicles that will be 90%-recyclable from 2002 onwards. PSA Peugeot Citroën is seeking to integrate recycling requirements from the design stage. In 1991, the Group initiated the Eureka Recap research programme to address the crucial problem of plastics’ recycling. In 2002, the final waste of the Group's new models will total less than 10% of the car's total weight.

The second part of the strategy is aimed at recycling end-of-life automotive parts and developing the re-use of certain parts. This objective will require the commitment and involvement of the Peugeot and Citroën sales networks. The Group has set up a network of Relais Vert Auto centres that accept automotive waste across France, and also in Spain, Switzerland, and Finland. The Secoia parts reconditioning programme is now being set up in France, following a successful trial, and will soon be extended to other European countries.

In the area of design for recycling (DFR), the PSA Peugeot Citroën approach is based on the commitment by the Engineering Department to reduce the diversity of materials, to increase the use of recycled materials and to facilitate the dismantling of ELV (DFD). Three main indicators have been developed to monitor the recycling performance of a vehicle during the design phase:

1. **Vehicle capacity for recovery.**

   In 2002, all new Peugeot and Citroën vehicles on the market will be recoverable at, at least, 90%. At present, the new Peugeot 607 exceeds this value by using only 5 materials family for 90% of its mass. The latter are metals (entirely recoverable, even in the case the precious metals in catalytic converters), glass, fluids (fuel, oil and ozone-friendly air-conditioning fluid), plastics (50% are polyolefines compared to 30% for the Peugeot 605, and composites parts can be shredded and reused in closed loop) and natural materials (9kg in total, 0.75% of the vehicle mass but 5.5% of plastics components). A strong emphasis has been put on the use of recycled materials, especially plastics parts (PE, ABS, fabrics). A 6% share of the plastics components are made of recycled materials.

2. **Vehicle capacity for depollution,** and

3. **Component capacity for depollution.**

---

33 Also based on written communications by Pascal Feillard (PSA Peugeot Citroen).
These indicators and their monitoring allows an optimisation of the depollution phase which limit the health and safety hazards and improve the capacity of the whole vehicle for recycling.

Peugeot 607 gives an example of the application of these design criteris. The full emptying of the fuel tank is prepared with specific marks on its bottom. The pyrotechnic equipment (pre-tensionners, airbags) are electronically neutralised in one operation. All the other operations (batteries removal, air conditioning fluid, etc.) have also been analysed and optimised, and a comprehensive booklet will be soon available for all the dismantlers in Europe.

PSA Peugeot Citroën has been and is still involved in research programs with other car manufacturers and suppliers.

Between 1991 and 1997, Recap, initiated by PSA Peugeot Citroën, Fiat, the raw materials producers Enichem (Italy) and DSM (the Netherlands), and equipment supplier Plastic Omnium Interior Automotive Components, a subsidiary of Visteon, looked at ways of increasing the amount of plastic recovered and recycled in order to reduce the quantities placed in landfill (see also Part III). The objective were three-fold: to incorporate recycling requirements into vehicle design and thereby to limit the production of plastic waste; to increase the use of recycled materials in the manufacture of new parts; and to develop new techniques for the recycling and re-use of plastics. The Recap programme has brought significant advances in recycle-friendly design and paved the way for new concepts and practical applications.

The main result on design grounds is a dashboard made from a single material. Dashboards traditionally comprise 20 main parts, made of five materials and put together through a complex assembly process. Before recycling, the different parts have to be separated – at prohibitive cost. To solve this problem, PSA Peugeot Citroën has teamed up with equipment supplier Plastic Omnium Auto Interieur to design a new monomaterial dashboard that is easier to recycle. This new concept has already been put into practice. The monomaterial dashboard will be fitted on a new PSA Peugeot Citroën vehicle in 1999.

Another challenge is to recycle the foam used in car seats. As part of the Eureka Recap programme, PSA Peugeot Citroën has identified two possible applications for recycled seat foam: it can be used in the petrochemicals industry to produce other plastic products, or it can be reintegrated into the manufacturing process and used for other automotive parts, such as soundproofing mats, bumpers and door panels.

By 2000, PSA Peugeot Citroën hopes that the results of the Recap programme will help it to recycle around 40% of the plastics contained in ELVs, i.e. between 45 kg and 60 kg depending on the model. This figure should be viewed against the 15 kg currently recycled, i.e. 16% of all the plastic parts contained in each car.

PSA Peugeot Citroën also participates to the development of EuCar-IDIS (see Part I and III) as well as other cooperative research programmes, and in particular:

(a) Valcor association. This association, including PSA Peugeot Citroën, Renault and Tier 1 automotive suppliers, evaluates the recycling potential of BMC-SMC parts. The dismantled parts are grinded and transformed in a sub-micron powder which is used in new automotive components creating closed loop recycling.
(b) Autovinyle association. This association also with Renault, recycling operators, raw materials suppliers has started to studies on the recycling routes of PVC. Some tons of PVC have been recycled and this is of a major interest since the vast majority of today ELV contains some percentage of PVC.

In the strategic area of ELVs treatment, PSA Peugeot Citroën has taken specific initiatives to develop recycling networks starting from ELV brought into the Peugeot and Citroën sales networks. The Group has set up a strict selection procedure for treatment and recycling firms involved in the cooperation. Candidates must agree to meet the objectives of the framework agreement, i.e. disassemble and decommission ELVs using environmentally friendly methods, destroy safety-critical parts so they cannot be re-used.

In France, the two organisations set up by the Peugeot and Citroën networks in France, Assainauto and Place’Nette, both founded in 1980, have signed in 1999 an agreement with Indra and ECO-VHU, two of the three French managers-distributors. These two companies manage the networks of certified dismantlers, collect ELVs from the networks and process them using environmentally friendly methods. The Group works with Qualicert-certified dismantlers. In Italy, Peugeot Italia and Citroën Italia have signed an agreement with ADA, the Italian official dismantlers network and they should join FARE very soon (before the end of this year). In Germany, Peugeot and Citroën Deutschland are developing a certified network of collecting points as required by the German voluntary agreement. At present, 145 Peugeot and 86 Citroën dealerships are certified.

A specific strategic development in ELV downstream operations is the reuse of car parts. Complementing the services provided by the Peugeot and Citroën networks as part of the Relais Vert Auto concept, Secoia extends the Group's commitments to collecting and re-using of end-of-life parts. Following full-scale trials, Secoia is ready for deployment in France and then Europe. By making the reconditioning of parts a major focus of recycling, the Group and will be able control the life cycle of its products. Reconditionable scrap parts (engines, gearboxes, transmissions, alternators, starters, etc.) undergo appraisal prior to collection from the Peugeot and Citroën networks and approved dismantlers. Once the parts have been selected and logged on a computer, they are sent to a regional logistics platform. A total of 20 regional platforms will be operational by July 2000. Parts are grouped by family and sent to the central platform at Hérimoncourt in Eastern France. Parts are reconditioned by the equipment supplier that produced them or by a special department at Faurecia, one of the Group's subsidiaries. On the basis of the detailed specifications drawn up by design offices, the reconditioning process and the quality controls, reconditioned parts can be used as standard replacement, and will carry the same carmaker's warranty as new parts. Reconditioned parts are brought back into the Peugeot and Citroën networks as standard replacement parts. These parts are certified by the carmaker and sold as part of standard replacement offers. They come with a one-year warranty, like new parts, but cost around 30% less. Secoia was first introduced in France in October 1998 and will be fully deployed by around July 2000. The Group intends to begin extending the system to Europe in 2000. Secoia was tested in the Rhône-Alps region in 1997 and 1998 by 34 Peugeot and Citroën dealerships and 36 ELV treatment companies. The trial period served to fine-tune management procedures and the follow-up of collected products and standard replacement ranges. Some 30,000 used parts were collected during this time.
II.2. Germany

II.2.1. The ELV problem

Germany is the major national automobile market in Europe with 3,735,987 new passenger cars registered in 1998 (26.8% of total EU15). The registrations in EU15 of new cars produced by the Germany-based car-manufacturing groups (BMW Group, Daimler-Chrysler, Opel, and Volkswagen Group) were 5,697,294 in 1998 (40.1% of total EU15). During the last few years, the mergers carried out by German car manufacturers (e.g. BMW on Rover, Daimler-Benz on Chrysler), brought Germany-based car producers to a central role in the global car market. Various factors, as the closeness of Germany to transition economies, can also reinforce this role in the future. Because their significance in Europe, German Carmakers had a great role in the debate about the ELV problem and regulation in Europe since its beginning.

The figures about the number of ELVs being scrapped in Germany are uncertain due to the lack of reliable statistical data. According to some estimates (see IPEE 1996), the number of ELVs in Germany was 2.6 million in 1994. Official figures indicate 3,392,358 cars deregistered in 1997. These estimates are considered as potentially misleading on the size of the ELVs market in Germany. There is a possibly huge difference between the number of cars deregistered and the number of ELVs for treatment due to significant export flows of ELVs to other countries. Figures on ELVs for treatment in Germany are being produced by ARGE-Altauto based on direct questionnaires to registration offices.

During the first part of 1990s, export flows of ELVs were recorded from Germany to Poland, former USSR states and other Eastern European countries, as well as France and the Netherlands (see IPEE 1996). These flows created concerns in the importing countries —were dismantling and shredding facilities are under pressure— and in Germany —were shredders and metal recycling industries have to face the disruption of inputs from a very significant source such as ELV. Recent analyses assume a number of 1.5 million ELVs to be treated domestically in 1995 and 2 million units in 2000 (Hooks 1999). Out of the about 3.3 million cars deregistered in 1997, the ELVs scrapped domestically are estimated at 1.5 million units (personal communications).

The export flows can be distinguished between flows for reuse as second-hand car and flows for treatment at lower costs.

The most important reason for ELV export flows is considered the down-selling of German deregistered cars as second-hand cars in other countries (personal communications). There is an enormous price difference between used cars in Germany and in Eastern European countries and former USSR states. For example, a BMW 316i (year of production 1978 and km 220,000) can have a value of 0/-150 DM in Germany and a value of up to 1,000 DM in Russia (personal communications)

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34 The analysis is also based on the interviews with Willi Adams and Luisa Ragher (Ford Europe), Wolfgang Fried (BMW), Hans-Guenter Jochum (Daimler-Benz), Martin Schenk (Arge-Altauto), Oliver Schulte (Org-Consult), Peter Zumboich (Adam Opel GA).
communications). The same argument also applies to potential ELVs from other EU countries. The relatively low standards for emissions prevailing in some countries can support the export market. It is estimated that 40-60% of cars deregistered in Germany during the last few years have been resold to other countries where they are mostly non-dismantled (personal communications). This evaluation is also based on the pattern of data on deregistration in Germany. Many deregistered cars are young cars (estimated 18% of deregistered cars have less than 10 years) with great value. High-level car deregistration peaks in the first 45 years according to a more general model of “car level-deregistration age”: the higher the market segment to which car belongs, the lower the age at which the car is deregistered. The demand for used spare parts also contribute to the export of not-too-old cars.35

Among the causes of transboundary ELV movements for cheaper treatment, the following are mentioned: the costs that last owners have to support in Germany for delivering ELV to dismantlers (estimated from 0 to 150 DM per car before the entry into force of the ELV Ordinance and voluntary agreement), the high costs of ASR landfilling, the cost advantage of Eastern European countries in labour intensive operations as dismantling, and the relatively less stringent regulations on dismantling and waste disposal in Eastern Europe. Before the recent developments on free take back (see below), Germany was in fact one of the few European countries were last owner is asked to pay (an estimated 50 to 100 DM on average) the dismantler that takes back his/her ELV. The cost of ASR disposal in Germany is estimated to range from 100 DM to 700 DM per ton compared, for example, to 50 to 70 DM in Greece. Dismantling cost is estimated at 1 DM per minute in Germany, compared to 0.20 DM in Poland (personal communications).

The above estimates can change the picture for ELV in Germany as well as in countries importing German ELVs. The number of “true” ELV to be processed domestically might be estimated even at half the official figure from deregistration, and the same applies for ELV processed abroad. A better understanding of ELV flows in Germany is expected as a consequence of the 1998 Altautoverordnung and the obligation ARGE-Altauto to monitor these data.

II.2.2. ELV policy developments

The process of ELV regulation in Germany has been very similar to the process at the EU level, and the latter both exerted and received influences by the developments taking place in Germany. The regulation process in Germany recently arrived at a compromise resulting from the co-evolution of the positions taken by the main actors, i.e. the Federal Ministry of Environment (BMU) and the involved industries (VDA and other 14 associations), on some critical points.

35 The export of these cars to developing countries founds a support by the demand of used and reconditioned parts. Many dismantlers in Germany have business relations with parts distributors in developing countries. It is estimated that than 50 % of used parts business is based on export. For example, the Mercedes-Benz Altteilecenter GmbH sells more than two third to foreign markets (personal communications).
Early developments: 1970s to mid-1980s

The definition of ELV and car recycling as policy problems began as early as the 1970s, in connection with the concerns caused by energy and material price shocks as well as the economic and environmental implications of the shift in car material mix. A series of studies on recycling and energy recovery potential of the different materials were produced and they set up many elements of the agenda for the debate on ELV occurring from the mid-1980s.

The foundations of a regulation on ELV and car recycling were set up in the Waste Avoidance and Waste Management Act of 1986 (WMA). The WMA established the duty for minimising waste generation and stated a priority of reutilization over incineration and disposal. WMA prepared the legal possibility of the Federal Government to issue statutory (Verordnung) and technical (TA Technische Anleitung) regulations on specific waste streams, announced the introduction of the producer liability for post-consumer waste (including take back and mandatory recycling) and announced specific measures on ELV. For the latter, the policy lines defined by WMA were the producer responsibility for the processing of ELV though a Verordnung and more stringent technical regulations on the disposal of ASR through a TA. After the WMA, the BMU issued, since 1990, various policy papers on ELV proposing the obligation by manufacturers and importers to take back their ELV without costs for the last owner, the reuse and recycling of parts and materials (including recycling rates) if technically and economically feasible, the provisions that car dismantlers must comply with, the consideration of waste prevention in new car conception.

A new impetus on ELV regulation came from the new waste policies of 1991 (Toepfer Law) which included “producer responsibility” and free-take back as the main reference principle. The draft Altautoverordnung presented in 1990 placed much emphasis on new vehicle conception and product durability. For ASR disposal, BMU published a draft technical regulation in 1992 (TA Shredderrueckstaende) that defined the maximum content of PCB and hydrocarbons in shredder residue for its disposal as ordinary waste, i.e. to avoid the disposal as hazardous waste. Neither the draft Altautoverordnung not the TA on shredder residue considered incineration as a good solution.

The German car industry developed a series of responses and alternative policy proposals. In 1988, a working group including car manufacturers, shredders, steel producers, and plastic producers began to discuss the problem of improving the processing of ELV and produced the “Concept for processing the end-of-life vehicles” on which VDA based its action at the policy level. The “VDA concept” accepted as the reference objective the need to reduce the amount and the toxicity of ASR and the possibility of increasing recycling of old cars. It was, instead, in strong disagreement with the indications of BMU on the ways to reach the objectives. In particular, the VDA concept, based on the "shared responsibility" approach, assigned the last owner the responsibility for disposal of the vehicle at the authorised dismantler with a fiscal advantage through the relief of ownership taxes, and it stated the need to maintain free market mechanism in the economic operations and transactions occurring in successive steps of ELV

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The analysis of policy developments prior to 1996 is largely based on Den Hond (1996), Chapter 6.
cycle (dismantling, shredding, metal recovery, etc.). The last owner thus will receive or pay money for his/her ELV according to market conditions. The need to maintain open the different options of ELV processing, including ASR incineration, was stressed together with the possibility to develop a national network for collection and disassembling of ELV. Finally, the VDA concept included the commitment to produce more recyclable cars and use more recycled materials but without the constraints of specific quantitative targets. Regulation on dismantling was deemed to represent a critical point of policy.

In 1991, VDA established a working group dedicated to ELV, the PRAVDA (Projektgruppe Altfahrzeug-Verwertung der deutschen Automobilindustrie) in which all the manufacturers were represented (Audi, BMW, Ford, Mercedes-Benz, Opel, Porsche, and Volkswagen). Through PRAVDA, a technical and political cooperation between carmakers developed. It involved the coordination of dismantling pilot experiences, the cooperation with material producers, the development of dismantling tools and information systems.

PRAVDA revised the VDA concept and elaborated the “Common concept for the recycling of end-of-life-vehicles (Gemeinsames Konzept zum Kfz-Recycling). The different versions of the concept were presented between 1992 and 1995. The revised “VDA concept” is very comprehensive and includes the technical and economic guidelines reflecting the view of industry on the most appropriate working of the ELV system. On the technical side, the drainage and dismantling activities should be organised to depollute ELV, separate reusable parts and all recyclable materials (glass, plastic, composites, non-ferrous metals were possible). The subsequent operations can take the shredder path or the “metallurgical recycling” path\textsuperscript{37}. In the first case, shredding give rise to the ferrous and non-ferrous fractions and to shredder light fraction. The latter, together with tyres, can be delivered for chemical recycling and/or energy recovery, with the remainder, composed of inert materials only, landfilled. In the metallurgical recycling path, steel is extracted and the inert residue is disposed. On the economic side, the VDA concept is based on shared responsibility between the industries involved and free market mechanism in the transactions taking place in the ELV chain. In particular, the last owner is expected to pay or receive a payment for ELV from authorised dismantlers according to the estimated value of the car (see also IPTS-JRC 1996). The VDA concept, as originally formulated, was extremely flexible from both the technical and economic side and can be taken as the clearest representation of the industrial approach to ELV. It includes in fact all the various options and the possibility of using market mechanism also were the PPP can be claimed to be applicable.

Around 1994, a convergence on some points emerged between the industry and the BMU. The most important change in VDA position was that recycling targets were accepted and they were the same introduced in 1993 in the French Accord Cadre as proposed by the ELV Project Group (ASR maximum 15% by 2002 and 5% by 2015). Furthermore, starting from 1994, carmakers began to sign private contract with large steel companies (e.g. Thyssen-Sonnenberg, Preussag-Recycling) that offered to organise nation-wide networks for processing ELV in an environmental sound way. To be profitable, these developments required strong technical and environmental regulation on car dismantling and shredding. At the same time, in the second draft

\textsuperscript{37} See Part I.
of *Altautoverordnung* of 1994, the BMU defined the ELV waste management as a ‘closed loop economy’ and, among the other provisions, included the possibility of incineration, established specific recycling targets (not-too distant from those proposed by VDA), involved parts and component makers as relevant agents of the Ordinance and provided for certificates of disposal to be released by registered dismantlers. An increasing attention arose about this critical phase of the ELV chain.

A fundamental disagreement between BMU and VDA remained, however, on two issues. The first one was the free take-back provision and, in general, the economic aspects of ELV, although the BMU left open the possibility to charge the value of FTB on the new car price. The industry claimed the appropriateness of “shared responsibility” as opposed to “producer responsibility”, thus proposing a distribution of costs according to market mechanism. The second point of disagreement was about the policy approach. The preference of car industry was for self-regulation of most of the economic and organisational aspects of ELV treatment through a voluntary pledge, while BMU preferred, as in the ordinance on packaging waste, direct and formal regulation also of these aspects.

**1996-98: the industry’s voluntary pledge and the Altautoverordnung**

In February 1996, the VDA and other 14 professional associations submitted a “Voluntary undertaking on ecologically compatible disposal and recycling of used motor vehicles in accordance with the German law on Recycling and Waste management”. The draft agreement avoids the product liability obligation and gives the industries involved a flexible framework for achieving the objectives of improving the processing of ELV based on self-initiative under economically efficient conditions. The general aims are:

- to design and produce cars in a way compatible with recycling,
- ecologically acceptable dismantling activities,
- to develop material cycles to improve the possibility of recycling and reduce the amount of shredding residue.

The instruments and commitments are the following:

- the creation of a nation-wide infrastructure for collection;
- the adoption of ecologically compatible procedures for removal of fluids, dismantling, recycling and recovery of parts from ELV;
- the adoption of targets for recovery so that the ASR is reduced to 15% by 2002 and to 5% of car weight by 2015;
- the appointment of a committee of VDA (the ARGE-Altauto) to coordinate the activities in the pledge;
- to report biannually to the BMU on the activities and results;
to take back, after the pledge is implemented, the ELV from the last owner though the collection stations of their manufacture at the terms and condition prevailing on the market;

- the commitment to improve the recyclability of the cars under the acknowledgement of the producer liability;

- to take-back free of charge the ELV marketed after the introduction of the recycling certificate if they are younger than 12 years from the first registration and subject to specific “normal” physical and technical conditions of the vehicle.

The pledge takes effect after the introduction of the appropriate regulatory framework on dismantling and shredding (i.e. Alauto-Verordnung) but it is deemed to be effective upon the acceptance by the Ministry of the Environment and the Ministry of Economic Affairs. The pledge was signed in March 1997 (see ARGE-Altauto 1997).

In June 1997, the German Bundestang approved the Ordinance on disposal of used motor vehicles, which was adopted by the Federal Government in November 1996 and approved by the German Bundestrat, subject to minor amendments, in May 1997. The ordinance entered into force on April 1st, 1998 (see German Bundestag 1997, Federal Ministry of the Environment 1997).

The ordinance establishes the requisite legal framework for improving the disposal of used motor vehicles in Germany and complements the voluntary pledge by defining the rules and regulations for those areas in which the voluntary measures are not possible. The ordinance is also aimed at establishing uniform condition for competition. The main objectives are to stimulate the ELV to arrive at the plants operating in an environmental way, to relieve the enforcement authorities from controls that are assigned to experts within a certification system, to define the standards for the collection centres, dismantling and shredding plants, for which it implies a whole series of new rules and obligations.

In particular, the last owner must deliver the ELV to an authorised dismantling/recycling plant, he/she receives a dismantling certificate that have to be presented when deregistering the vehicle. The owner of the used vehicle can receive a positive price for the vehicle or have to pay a fee depending on the condition and age of the vehicle when delivered at the dismantling plant. The ordinance takes into account the voluntary pledge by industry and its commitment to

38 “Voluntary Pledge regarding the Environmentally Compatible Management of End-of-Life Vehicles (Passenger Cars) within the Concept of the Ecocycle Act”. The associations participating to the voluntary pledge of March 1997 are the following: German automotive industry (Verband der Automobilindustrie e.V.-VDA); automotive importers (Verband der Importeure von Kraftfahrzeugen e.V.-VDIK); car dismantlers (Interessengemeinschaft der Deutschen Autoverwerter-IGA); steel recycling industry (Bundesverband der Deutschen Stahl-Recycling-Wirtschaft e.V.-BDS); association of scrap recycling and management (Deutscher Schrottrecycling Entsorgungsverband e.V.-DSV); automotive traders (Zentralverband Deutsches Kraftfahrzeuggewerbe e.V.-ZDK); metal traders (Verein Deutscher Metallhändler e.V.-VDM); rubber industry (Wirtschaftsverband der Deutschen Kautschukindustrie e.V.-WdK); steel industry (Wirtschaftsvereinigung Stahl-WV Stahl); metal industry (Wirtschaftsvereinigung Metalle-WV Metalle); plastics producing industry (Gesamtverband kunststoffverarbeitende Industrie e.V.-GKV); plastics processing industry (Verband kunststoffverarbeitende Industrie e.V.-VKE); sheet glass industry (Fachvereinigung Flachglasindustrie e.V.); automotive parts traders (Gesamtverband Autoteile-Handel e.V.-GVA); textile industry (Gesamtverband der Textilindustrie in Deutschland - Gesamttextil e.V.); brake and clunch lining industry (Verband der Reibbelagindustrie e.V.-VRI).
take back the vehicle. Therefore, it does not impose statutory provisions on take back of vehicles as required by Section 24, Par. 1 of the German Law on Recycling and Waste Management. The possible payment of take-back is thus left to the dealers/manufacturers commitments (German Bundestag 1997).

A set of detailed obligations regards the dismantlers/recyclers, the collectors, and the shredders. Collection centres and dismantling/recycling plants have to be authorised. The dealers of the carmakers can operate as authorised collection centres. The technical provision for collectors and dismantlers are stringent in particular on removal of used oils and liquids and on dismantling of different parts and components. In particular, dismantlers have to remove large plastic parts, wheels, front, rear and side windows, seats, all parts containing copper. The dismantler have to assure that by 2002 the proportion of parts, materials and operating fluids are at least 15% of the weight of used motor vehicle.

The rest of the car has to be delivered to an authorised shredder. The latter, further to comply with general regulations, must reduce the disposal of waste accumulated during the shredding process to 15% of the net weight of vehicle before pre-treatment and disassembling by 2002 and to 5% by 2015. The possibility to energy recovery is not excluded.

The collectors, dismantlers/recyclers, and shredders have to be certified by experts operating according the corresponding German regulations or an accredited agency of certifications on quality management according to standards of the ISO family. A reform of the procedure for registration and deregistration of cars in accordance with the above provisions is introduced.

The accompanying notes of the Ordinance (see German Bundestag 1997) specify that the ecological disposal of ELV may give rise to additional costs but they can be met by the saving of disposal costs and the possible development of a reuse/recycling material cycle. The problem of incremental cost is mostly in the short term and will gradually decrease in the long term.

The view by the BMU on the ordinance (Federal Ministry of Environment 1997) is that, together with the voluntary pledge, it can assure a competitive environment because the access to operators fulfilling the requirements of regulation is not prevented. In fact, it is expected that, in addition to the partnership between the carmakers and dismantlers, there is the possibility of coalition between collectors and dismantlers outside the control of carmakers. This will ensure market-oriented prices.

One important aspect of the ordinance is that it applies also to ELV to be exported for recycling. The certificate of destruction must be obtained also by foreign dismantlers and recyclers; the foreign dismantler and shredder have to be authorised and certified according to the rules. Furthermore, the regulations arising from the EU Directive on export of waste applies, and the car have to be depolluted from liquid and fluids before export in order to be in the Green List of Waste.

The entry into force of the Ordinance on April 1st, 1998 allows also the take off of the voluntary pledge by industry and in particular the start up of the collection system at the nation wide level and the authorisation procedure of dismantlers and shredders. The first results observed between 1998 and 1999 are in fact the development of a good infrastructure for tack back, increasing information on collection, dismantling, and the development of the certificate system,
which is reported to be very rapid (personal communications). In July 1999, the German Government reported to the Germany’s Parliament that crucial aspects of the Voluntary Agreement have already been set up and that the Government is (despite of some critical aspects in the Ordinance) fully supporting the "German approach on car recycling" (i.e. Ordinance and Voluntary Agreement).

A flexible compromise
The German system represents an example of compromise between voluntary actions and regulation. Mainly voluntary in nature are the actions on car design and the organisation of the economic and networking relationships between car and material producers and collection/dismantling/shredding industries with the aims of waste reduction and environmentally sound treatment of ELVs, in particular depollution. Mainly regulatory in nature are the standards and procedure for the technical activities occurring in collection/dismantling/shredding plants as well as in deregistration and other administrative aspects involving the last car-owner. The German approach to FTB is clearly a compromise in that, while it exists, it is voluntary and subject to conditions aimed at preventing from “free lunch” and huge financial transfers not corresponding to actual dismantling incremental costs. The non specifications of recycling targets as opposed to specific recovery targets, which implies non-constrained ASR energy recovery levels, is another compromise solution leaving the car and material industry a significant element of flexibility.

The compromise and flexibility features of the German approach may be at the root of the strong opposition that the German car industry exerted on the EU Directive proposal which is more rigid in many respects and in particular on economic grounds (see Part I and III)39. The same applies to the strong opposition by German carmakers to the Dutch model based on disposal fees and financial transfers from the consumers to dismantlers/recyclers. According to the evaluations by most German carmakers and experts, the EU model and the Dutch model can both have the effect of displacing and weakening the practical implementation of the German model (see also the discussion in Par. III.6).

II.2.3. Industrial initiatives

The process of regulation/policy formation was paralleled by an extensive exploration of the possible industrial solution to ELV problem which took place through: (a) the cooperative framework of VDA/PRAVDA initiatives described above and those taken more recently; (b) the networking activities between different industries involved in ELV; (c) the initiatives at individual car company level.

39 During 1998-99, the strong German opposition to some provisions of the EU Directive caused criticisms to the BMU for not supporting enough the EU Directive.
PRAVDA 2 and ASR recovery

The PRAVDA 2 project (1993-98) was primarily addressed to explore the best options of plastic recycling from ELV from the technical, economic and environmental points of view (Hoock 1999). The Participants to the projects were 30 companies including the main German car producers (BMW, Opel, Audi, Ford, Mercedes-Benz, Porsche, Volkswagen), Renault and Peugeot, the major European companies of the chemical and polymer industry, and companies operating in dismantling and recycling. The project explored in particular the total process chain for the mechanical recycling of plastics from ELVs at the industrial scale. The investigated plastics were ABS, PA, PE, PP, PMMA, and PUR each studied by a sub-group.

From a purely technical point of view, out of the 75,000 tons of plastics contained in ELV processed in Germany in 1995 (1.5 million units with 50 kg of plastics each), around 30,000 tons (40%) are considered suitable for mechanical recycling (see Table II.2.1). In the year 2000, with an estimated 2 million ELVs each containing on average 70 kg of plastics, the technically feasible potential for mechanical recycling is estimated at 56,000 tons or again 40% of total content.

Table II.2.1.
Potential for mechanical recycling of plastics from ELVs in Germany (1995)

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Proportion of removable components (average, kg/vehicle)</th>
<th>Material potential from 1.5 million ELVs (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>3.0</td>
<td>4,500</td>
</tr>
<tr>
<td>PP</td>
<td>5.0</td>
<td>7,500</td>
</tr>
<tr>
<td>ABS</td>
<td>3.0</td>
<td>3,000</td>
</tr>
<tr>
<td>PA</td>
<td>1.0</td>
<td>1,500</td>
</tr>
<tr>
<td>PUR flexible foam*</td>
<td>7.0</td>
<td>10,500</td>
</tr>
<tr>
<td>RIM components*</td>
<td>0.2</td>
<td>300</td>
</tr>
<tr>
<td>PMMA</td>
<td>1.4</td>
<td>2,100</td>
</tr>
<tr>
<td>Total (technical feasibility)</td>
<td>19.6</td>
<td>29,400</td>
</tr>
</tbody>
</table>

* Including feedstock recycling methods for polyurethanes


A mixed picture emerges for the actual exploitation of the technical potential. The mechanical recycling of some plastics can be feasible depending on local technical, economic and ecological aspects. In particular, there are specific requirements for the different plastics regarding the scale of operations (adequate availability of plastics for recycling), quality, marketing potential for recycled materials, adequate cost-benefit ratio. In particular, in a system with seven groups of plastics materials coming from a great number of dismantlers in Germany, the possibility of adequate material flows for processing without a very costly logistic infrastructure is greatly reduced. The most adequate scale is for PE, PP and PUR. The quality of material with recycling content offers only limited scope for their use in the original applications and
alternative applications have to be considered. The economic balance largely depends on the purity of materials dismantled and delivered for recycling and a lot remain to do in this area. The result is that mechanical recycling alone cannot allow reaching the non-disposal targets for ELV in Germany and a combination of mechanical recycling, chemical recycling and energy recovery has to be considered. In essence, not differently from the results of other studies (see RECAP 1997, APME 1998), economic and organisational considerations prevent the possibility to exploit the technical potential for mechanical recycling from ELV.

There is an on-going cooperation between car producers in Germany for ASR reconditioning and use as a substitute of heavy oil; it involves 80,000 tons of ASR. Arge-Altauto support experiences for recovery, spending several million DM. The process is based on the separation of organic fraction, recovery of copper (copper contained in ASR can have a value of 65 DM/kg), recovery materials for road construction (polypropylene fraction is economic to recover for this use). If the innovative solution will be workable, only 1% of ASR will be disposed of by using it in blast furnace for iron 40.

**Networks of industrial interactions**

At the level of network interactions between the different industries involved, the very articulated German experiences developed through two general patterns 41.

The first one was dominated by the concerns by German shredders, and metal recyclers/producers about the instability of raw material supply from ELV, also triggered by export of ELV to other countries. In early 1990s, large steel companies as Kloeckner, Preussag and Thyssen-Sonnenberg signed private contracts with car manufactures for organising the processing of ELV according to rigorous environmental standards. In this way, the shredders/recyclers took some form of control over dismantling by organising dismantling networks based on bilateral individual contracts. An example is the agreement between PRG (Preussag), and Volkswagen/Audi of 1994 42. Four parties were involved in the agreement: PRG, VW/Audi, VW/Audi dealers, associated car dismantlers. The dealers are bound to take back ELV from last owners at market conditions (or, for some models, free of charge), provide a certificate of disposal and prepare the cars for delivery to PRG recycling centres. PRG is bound to build up a network of recycling centres, supply them with up-to-date technologies, assure environmental standards, and accept materials and parts from ELV for recycling. The PRG recycling centres are bound to accept the car from the VW/Audi dealers under market prices and perform the treatment. VW/Audi is bound to accept specified plastic parts from disassembling, accept spare parts for reconditioning and sale, and reuse some materials, parts and components.

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40 Daimler-Chrysler, Recycling department, personal communication to IDSE-CNR, 1999  
41 A detailed description of the industrial networks in Germany before 1996 can be found in Den Hond (1996).  
42 Recently, MAS/Mosolof, a leader in new car transportation in the distribution system, took the place of Preussag. It also owns two dismantling facilities and have made offers to various car manufacturers to build up a collection/recycling network as a full service provider (personal communications).
The other pattern is based on the creation of an independent car dismantler network associated to car producers. This is the approach followed by BMW, Opel and Ford. The car dismantlers in the network are bound by individual bilateral contracts specifying the technical profile of operations and the control system. In the case of Ford, the car dealers are also involved in the agreement through a mechanism of discount for old cars and the obligation to deliver ELV to the dismantlers in the network.

Seven Japanese car manufacturer (Daihatsu, Honda, Mazda, Nissan, Subaru, Suzuki and Toyota) are working together in the MARI. (Marktübergreifende Automobil-Recycling Initiative), founded at the beginning of 1993. MARI is co-ordinating and managing the activities to fulfil the legal and voluntary obligations in Germany, mainly to build up the take back and dismantling network. MARI is licensing the dismantler, providing dismantling instructions, support dealers to be certified as a take back point. Currently around 100 dismantler are in the system and about 75% of the around 4,500 dealers (all car manufacturers). MARI has also signed a contract with Preussag in 1995. The take back of ELVs is done on free market conditions.

The specific experiences of Adam Opel AG, BMW, Daimler-Benz, and Ford are examined below on the basis of direct interviews and other documents.

II.2.3.1. Adam Opel AG

The ELV management experience at Adam Opel AG includes the two main directions of ELV recovery and car design. The development of waste management at the dealership and service-points level as well as the recycling of material waste during manufacturing integrates the ELV strategy (Adam Opel AG 1999).

At the post-consumer recovery/recycling level, Opel started in 1992 to advise and audit vehicle dismantlers on ELV treatment. The contract-based network of associated dismantlers included 234 companies in 1998 spread all over the country.

The associated dismantlers are supplied with dismantling manuals for the different models that are tested internally by Opel. Their work is verified directly by Opel through annual visits, also in accordance to the requirements of the 1998 Ordinance. In the recent past, due to lack of compliance and the selling of ELV on “secondary market” as used cars, many dismantlers were expelled from the network and their number passed from approximately 400 to the current 234 (personal communications).

The main advantages for associated dismantlers are that they receive information on legal aspects by carmakers, are supplied with instructions on buying equipments for their operations, they are advised and helped in selling parts and materials from dismantling. The supporting activities developed by Opel include an information system on dismantling, the making of

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43 The attempt for a direct interview with Volkswagen was unsuccessful. The experience at Volkswagen before 1996 in analysed in some details by Den Hond (1996).
dismantling studies, and the elaboration and up dating on dismantling information and manuals. A cooperation with Renault and Daimler is going on to dismantle also cars not of Opel make.

On the design level, Opel developed DFR manuals, which include DFD, for the internal use of engineers. The manuals have been introduced five-six years ago and they are continually evolving. They specify the possible technical solutions for improving recoverability and recyclability, including what materials to use under feasibility conditions. On the dismantling side, a specific attention is addressed to facilitating the removal of fluids and parts containing harmful substances to be recovered (e.g. batteries, air bags, and seatbelt pretensioners). In 1979, Opel was the first carmaker to introduce a system of coding for every single plastic part to facilitate their separation at dismantling. For material choice, a specific hierarchy is suggested that reflects technical and legal requirements. For example, PVC is not excluded from the material choice but its use is suggested in a way that a possible PVC banning will involve mainly cables and ceilings and not many parts and components. The current material composition of Opel vehicles is reported in Table II.2.2.

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage of total weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating fluids</td>
<td>5.3</td>
</tr>
<tr>
<td>Electrical</td>
<td>0.5</td>
</tr>
<tr>
<td>Other materials</td>
<td>5.9</td>
</tr>
<tr>
<td>Process polymers</td>
<td>1.4</td>
</tr>
<tr>
<td>Polymers</td>
<td>15.5</td>
</tr>
<tr>
<td>NF metals</td>
<td>1.6</td>
</tr>
<tr>
<td>Lightweight metals</td>
<td>3.3</td>
</tr>
<tr>
<td>Steel/iron</td>
<td>66.5</td>
</tr>
</tbody>
</table>

Source: Adam Opel AG (1999)

Recyclability coefficients, which include economic variables together with the technical ones, are calculated for internal use. One of the main suggestions emerging from DFR manuals is to reduce the number of plastics and to use them in pure form. There are strong limitations, however, in the attempt to avoid composite materials and the engineers are looking at those composites that are compatible in a joint recycling process.

The cooperation with component producers for developing DFR is strong, in particular with plastic producers (personal communications). Although the development of recyclability is a problem of carmakers, it can be “transferred” partly to suppliers through the contractual specification on materials, parts and components.

Integrated with DFR is the development of “closed loop” use of recycled materials, in particular plastics, in new cars. As early as 1990, recycled plastics were used in components in the Calibra. The use of recycled plastics in Opel cars was 11,000 tons in 1995 and reached 30,000...
tons in 1998 (Adam Opel AG 1999). The up-ward trend is expected to continue in the next years. Currently, Opel has specified 45 different types of recycling plastics that have been tested in various applications before approval for integration in car manufacturing. Another 25 types are under testing procedures. Some of the applications are the air filter housing, the air ducts, the hoodliner and various cable ducts. Bumpers and battery cases are subject to cascade recycling by becoming fendlines or bumper carriers.

The dealers and service points of Opel are involved in a system of management of the waste arising from their operations (e.g. repair) which is operating since 1995. The system gave rise in 1997 to collection and treatment by Opel disposal partners of 14,000 tons of materials coming from car maintenance and repair (including bumpers, batteries, tyres, glass, paper, filters, waste oil, brake fluids, refrigerants) (Table II.2.3). Opel is preparing the application of such system to its dealers/service points all over Europe.

Table II.2.3.
Collected and processed waste from Opel dealers and service points in Germany, 1997

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumpers</td>
<td>900</td>
</tr>
<tr>
<td>Batteries</td>
<td>2,000</td>
</tr>
<tr>
<td>Tyres</td>
<td>1,500</td>
</tr>
<tr>
<td>Multilayer glass</td>
<td>1,200</td>
</tr>
<tr>
<td>Paper/cardboard</td>
<td>3,700</td>
</tr>
<tr>
<td>Filters</td>
<td>1,200</td>
</tr>
<tr>
<td>Styrofoam</td>
<td>40</td>
</tr>
<tr>
<td>Blended materials</td>
<td>200</td>
</tr>
<tr>
<td>Waste oil</td>
<td>2,5000</td>
</tr>
<tr>
<td>Brake fluid</td>
<td>300</td>
</tr>
<tr>
<td>Refrigerants</td>
<td>200</td>
</tr>
</tbody>
</table>

Source: Adam Opel AG (1999).

In Opel plants, manufacturing waste is collected and separated. Around 1,200-1,500 tons of stamping waste arise from the manufacturing of instrument panel carriers and it is remanufactured to become, for example, centre consoles of the Omega (Adam Opel 1999).

An extensive activity of components’ remanufacturing is carried out. It involves parts collected at service points and dealers (e.g. starter motors, engines, cylinder heads of clutches) and deliver for repair at Opel plants or at contractors and then re-employed with unlimited guarantee. Also catalytic converters are reclaimed extracting precious metals.
Opel performs Life Cycle Assessment (LCA) involving materials and components. The experience started some years ago, also in the framework of the LCA project of EUCAR/ACEA, but it is not yet fully integrated into the definition of hierarchies and choices of DFR. An example of LCA at Opel is about the choice between steel and magnesium for the Astra cross car beam (Adam Opel AG 1999). In cooperation with Norsk Hydro, the energy/emission balance of the two materials was studied considering the stages of mining, raw material production, material processing, beam manufacturing, transportation, vehicle use over its life and ELV treatment. The method is also based on DIN EN ISO 14040 standard of 1997. The results show that, although magnesium requires three times more energy in production than steel, if hydroelectric power is used the proportion fall to 40%. Given the lightness of magnesium, the energy use during car life gives an advantage to it. As a result, over 53,000 km the two materials are almost equivalent in terms of greenhouse gas impact but over 150,000 km magnesium gives an advantage. By introducing other criteria, e.g. the different recyclability of the two metals, however, new bases for evaluations arise and different recommendations may come. The same applies to safety criteria.

II.2.3.2. BMW

At the beginning of 1990s, BMW started an active strategy on ELV and car recycling that includes a network of associated dismantlers and a great emphasis on design for dismantling and recycling (BMW 1996 and 1997, personal communications).

Starting from the first agreement with one dismantler in 1991, the associated dismantlers of BMW have currently reached the number of 90. They are also involved in the reciprocity agreement with FIAT, Renault, and Rover. The bilateral contracts specify that the dismantler have to remove fluids, battery and tyres as well as specific plastic materials (as PA and ABS) and deliver these parts and materials to specific recycling companies or to BMW Recycling and Dismantling Center (RDC). The technical and environmental requirements for dismantling are also specified, and independent as well as BMW experts will supervise dismantlers regularly. The objective is to expand the network up to 150 partners in the next few years.

Since beginning 1997, BMW accepts all end-of-life vehicles of BMW make at its own associated dismantlers free of charge if the vehicle is not older than 12 years, whereas in the case of cars older than 12 years the market conditions applies. If the value of old car exceed the cost of recycling, the owner is paid for the difference.

In 1994, BMW established a reciprocal cooperative agreement with FIAT and Renault for using their respective dismantling networks. In 1995, Rover joined the agreement. BMW offers its dismantling network for ELV of FIAT, Renault and Rover make in Germany. At the same time, dismantlers associated to FIAT, Renault and Rover in their countries accept BMW ELVs (see also the analyses of France and Italy). Recently, BMW licensed a dismantling partner in the USA and three dismantling partners in Japan.

The DFR and DFD approaches at BMW have been developed starting from the Recycling and Dismantling Center (RDC) of Lohof operating from 1994 (after the experience of dismantling
pilot plant in 1990) and the activities at the Engineering Center (FIZ) of Munich. “Dismantling parts charts” are systematically developed which contain the guidelines and recommendations for designers. The practical development and testing of dismantling technologies is also performed and it give rise to a series of interactive exchanges with various other functions in the company as well as dismantlers in the network in order to optimise the results. The system is based on dismantling modules and the measurement of dismantling time, weight of parts, and other cost sensitive elements. A specific activity is carried out on fluid drainage. A system for plastic-type identification based on infrared technology has been developed for the car models produced when the current system of parts marking was not still in use. A project of RDC is the compilation of the international databank (IDIS - International Dismantling Information System) which contains a data, dismantling handbook and instructions, information on dismantling times, materials and other aspects of the dismantling process. The project is in cooperation with other car manufacturers and is designed for dissemination in Europe.

On the practical side, the developments of DFD implied various specific adaptations in BMW car making. One example is the front grill that is currently composed of two plastic components clipped together and easily to separate compared to the traditional system based on a number of studs in aluminium and plastics that required a time-intensive process of disassembling.

The DFR approach is very comprehensive and involves an articulated system of guidelines on design (e.g. structure of the component), material mix and assembling (e.g. technique of joining) together with guidelines on the integration of the components in the product making.

Recycling coefficients have been developed based on indices of “suitability for recycling” of the components and parts. The indexes are based on the ratio of costs for new materials and disposal on the costs for dismantling reprocessing and logistics expressed in percentage (see BMW 1996). The different components are therefore classified according to a matrix of suitability including three recycling classes reflecting technical and economic criteria (Table II.2.4). The presence of “problem materials”, i.e. those included in the BMW S 113 89.0, places the component in the lowest class of suitability which is that to be avoided in the design of future components.

The inclusion of recyclability criteria in product design and development is illustrated in Table II.2.5. The recycling requirements, including the desired recycling quota, are first introduced at the level of whole car conception. They are then developed at the stage of concept development in which the consideration of the energy-emission balances of the components, the dismantling analysis, the BMW norms and recycling prescriptions are considered. Finally, the recommendations enter the phase of “series design” in which control lists and check systems are used to ensure the achievement of the objectives.
Table II.2.4. Components’ recyclability evaluation matrix

<table>
<thead>
<tr>
<th>Recycling classes</th>
<th>Hazardous materials *</th>
<th>Release for recycled materials</th>
<th>Technical and economic suitability*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class R1</td>
<td>none</td>
<td>Given</td>
<td>&gt; 100%</td>
</tr>
<tr>
<td>Class R2</td>
<td>none</td>
<td>Not possible</td>
<td>80-100%</td>
</tr>
<tr>
<td>Class R3</td>
<td>existing</td>
<td>Not evaluated</td>
<td>&lt; 80%</td>
</tr>
</tbody>
</table>

* In each case the lowest value determines the overall classification of the component.

Suitability index = \( \sum \) costs for new material and disposal / \( \sum \) costs of dismantling, reprocessing and logistics

Source: BMW (1986) and personal communications.

Table II.2.5. Integration of recycling criteria in the product development process

<table>
<thead>
<tr>
<th>Development phases</th>
<th>Target definition</th>
<th>Concept phase</th>
<th>Series development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Worksteps</strong></td>
<td>Planning assignment</td>
<td>Concept development</td>
<td>Project approval</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selection of alternatives</td>
<td>Series development</td>
</tr>
<tr>
<td><strong>Decision milestones</strong></td>
<td>List of targets</td>
<td>Concept program</td>
<td>Release for production</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Project program</td>
<td></td>
</tr>
<tr>
<td><strong>Job packages of the various phases</strong></td>
<td>Defining main criteria of environmental compatibility (EC) on overall vehicle level</td>
<td>Determining EC on component level</td>
<td>Continuos application of data by checklists and assessments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conducing dismantling analyses</td>
<td>Target actual harmonisation of recycling rates and other input data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Determining dismantling rates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Determining desired recycling rate</td>
<td>Classifying recycling requirements</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compiling a life-cycle analysis and energy balances</td>
<td></td>
</tr>
</tbody>
</table>

Source: adapted from BMW (1996).

A great deal of interaction is developed with component producers that are involved through contracts in the achievement of recycling objectives. Specifications of the recycling and waste features of the components are applied in suppliers’ contracts that are subject to specific BMW norms. The requirement of reutilization of material in closed loop cycles, especially in the car production itself, is also included according to the volume of supply (see BMW 1996).

Various practical changes occurred as a consequence of the above developments. One example is the shift to aluminium only heat insulation of the car underbody; another example is the
recycling optimised dashboard of the BMW 5 series that currently uses a single material system based on polyurethane (PUR) instead of the old non-recyclable mixture.

The reuse of recycled plastics in new cars is being developed. The sliding/tilting sunroof is now made of reprocessed sheet mould compound (SMC) recycled from old bumpers, an innovation developed internally. In the BMW 3 series, 65 components have been released that are made of recycled plastics. In the BMW 5 series, the recyclated use was increased from 2.5 kg to 24 kg corresponding to a use of 15% of total amount of plastics in the car.

LCA is used to compare the relative environmental performance of the components and materials. It is considered in the DFR to some extent (personal communications). An example is the relative merit of steel and aluminium in terms of energy consumption for the rear axle of the 5 series (see BMW 1996).

A system for recovering the waste materials arising from BMW repair and service shops (used oil, air filters, batteries, etc.) in Germany has been developed in cooperation with CCR Component Recycling GmbH.

II.2.3.3. Daimler-Chrysler

After the definition of environmental management functions in 1988-90, Daimler started the process of experimenting recycling on Mercedes cars in 1991. An extreme difficulty in finding ELV of Mercedes make emerged that, in the following years, stimulated an extensive investigation of the actual deregistration behaviour in Germany and the other EU countries. Compared to an average of 400,000 cumulated deregistrations of Mercedes car in the EU, the actual number of ELV is estimated at 25,000. The data in the different countries are summarised in Table II.2.6 (personal communications)\textsuperscript{44}.

In 1999, about 6,000 Mercedes ELVs (categories M1 and N1) have been estimated in Germany based on a panel of 60 dismantlers that can be compared to around 300,000 Mercedes of the same categories deregistered (personal communications).

The reasons for the huge differences are in the deregistration procedures in various EU countries, including Germany before the ELV Ordinance, that allows to down-sell reregistered cars in another countries. Mercedes cars deregistered in Germany are for the 55% younger than 12 years, and in some cases very young, and most of them are sold to other EU countries and non-EU countries as well (Eastern Europe, North Africa, and Middle East).

\textsuperscript{44} For the corresponding estimates at EU level see Part I.
Table II.2.6. Recognised ELVs of Mercedes make in 1995

<table>
<thead>
<tr>
<th>Country</th>
<th>Estimated number of actual ELV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>about 15,000</td>
</tr>
<tr>
<td>Denmark</td>
<td>negligible</td>
</tr>
<tr>
<td>Finland</td>
<td>about 100</td>
</tr>
<tr>
<td>Sweden</td>
<td>about 200</td>
</tr>
<tr>
<td>France</td>
<td>500 to 1,000</td>
</tr>
<tr>
<td>Italy</td>
<td>negligible</td>
</tr>
<tr>
<td>Spain</td>
<td>200 to 500</td>
</tr>
<tr>
<td>UK</td>
<td>500 to 1,000</td>
</tr>
<tr>
<td>Austria</td>
<td>about 50</td>
</tr>
<tr>
<td>Total UE</td>
<td>about 25,000</td>
</tr>
<tr>
<td>Memo: officially deregistered</td>
<td>400,000</td>
</tr>
</tbody>
</table>

Source: personal communications.

The local-level Daimler-Benz workshop and service points are involved in the Mercedes Recycling System for collecting parts scrapped during maintenance for reuse. Around 1,200 workshops are involved in the system. 15,000 metric tons of material will be collected in 1999 from the workshops, more than 96 % will be recovered and re-used, corresponding to a re-use and recycling rate of 87 %.

Most of the activities on ELV at Daimler-Benz are at the level of DFD and DFR. The DFR/DFD activities began 1989 with research and development in the field of plastic recovery and whole-body recovery (the "metallurgical recycling" concept, see Part III). Two departments began working in parallel, the LCA Department and the DFR Department, based on the above-mentioned experiences, the cooperation with the university of Stuttgart, ETH Zurich, MITI, and the knowledge gathered from cooperation in PRAVDA and ACEA/EUCAR. In 1996 the activities were combined one single department.

Mercedes Benz Passenger Cars produces DFD/DFR guidelines for internal use only. They includes also references to the European guidelines deriving from discussion with other producers at ACEA to be produced end-1999.

In general the current developments on DFD/DFR point in the direction of simplify the material regime by reducing the number of plastics. One specific prescription is to reduce PVC
whenever possible. Mercedes cars contain only 15-20% as much PVC as as cars of other brands. PVC has been phased out from the underbody coating and still remains only in the cables systems (Daimler-Benz 1998). The process of freeing the car from PVC is positive also at the recycling stage because PVC become tight with steel and chlorine contained in PVC go into the organic fraction. Among the DFR guidelines is the prescription that 20% of plastics in new cars should be based on recycled materials. In particular, recycled plastics are used to mix and upgrade PP thermoplastic elastomers used in bumpers. One innovative development is that Daimler is addressing the possibility of an extensive use of sisal and other natural fibres (Table II.2.7). They are very light and recoverable and have a high energy content (Daimler-Benz 1998; personal communications).

Table II.2.7. Natural fibres in Mercedes cars

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backing for interior door trim</td>
<td>Flax, sisal</td>
</tr>
<tr>
<td>Front/back seats-upholstery</td>
<td>Coconut fibres, animal hair, latex</td>
</tr>
<tr>
<td>Roof lining trim</td>
<td>Cotton, wool</td>
</tr>
<tr>
<td>Head restraint lining</td>
<td>Cotton, wool</td>
</tr>
<tr>
<td>Part of C-column trim</td>
<td>Cotton, wool</td>
</tr>
<tr>
<td>Part of center console trim</td>
<td>Cotton, wool</td>
</tr>
<tr>
<td>Instrument panel trim</td>
<td>Cotton, wool</td>
</tr>
</tbody>
</table>


Among the results of DFR and LCA are innovations in copper recovery from old cars and the substitution of water based paints for solvent based paints.

The development of DFR requires a lot of interaction with component producers. At the technical level, the development of new conception of components and materials can create also resistance by suppliers that are, however, bounded by technical specifications. The latter do not, in general, establish the use of recycled materials in new components, as is made, instead, by Chrysler —part of Daimler from 1998— in the USA, where also the use of recycled oils is specified in the contracts. Component producers must also deliver information for LCA.

LCA is made at Daimler-Benz in evaluating material concept alternatives. The analysis includes all the life cycle for the specific car model but some parameters are not agreed upon. The criteria are a combination of environmental impact, economic feasibility, and technical feasibility. LCA suggests that a lot remain to be done for reaching equilibrium between more recyclability and less emissions. Optimising is needed for most of the parts and the LCA of materials can supply results different from those expected about their relative merits for emission impact.
II.2.3.4. Ford Motor Company\textsuperscript{45}

Ford is working on ELV recyclability and DFE/DFD/DFR since 1985.

At worldwide level, Ford applies: (a) restrictions on hazardous substances since 1985; (b) design-for-recycling guidelines since 1993; (c) parts marking/material coding standards since 1993; (d) a vehicle recycling strategy since 1994 -- with numerical targets for the overall recyclability of new models, the use of recycled content materials and the elimination/substitution of hazardous materials.

Ford adopted Restricted Substance Management Standards WSS-M99P9999-A1. The purpose of this standard is to inform Ford Suppliers and Ford Personnel of restrictions pertaining to certain substances which, by regulation or by Ford direction, shall be restricted or excluded from 'products' supplied to Ford or for use in Ford products.

The Design-for-Recycling Guidelines, which are communicated to suppliers as well as Ford engineers, are focused on 3 key areas and basically require a more pro-active approach on the vehicle overall design.

The specific section of the guidelines for fasteners includes:

- the use of the minimum bolt/nut/screw/dead/drive types and sizes;
- the use of fasteners of ferrous materials unless product integrity is impaired;
- the incorporation of compatible materials; the design of fasteners to allow easy removal of components.

The section on material selection includes:

- the control or elimination of materials posing potential risk on human health and the environment;
- the use of recyclable materials with a preference for those having a circuit for collection;
- the request to suppliers to demonstrate recyclability of their material/component and to take back material for recycling at the ELV stage;
- the avoidance, if possible, of materials which are not compatible for recycling\textsuperscript{46};
- the assessment of the perception of PVC in the image of new car models;
- the standardisation of material types and the use of fewer material specifications when feasible;

\textsuperscript{45} Ford’s production activities are spread in various European countries, with a concentration in Germany and the United Kingdom. The choice of including the Ford case in the analysis of Germany comes from the specific reference to activities in Germany.

\textsuperscript{46} More in details, the scale of preference is: (a) most preferable: to select the same material type and grade; (b) less preferable: to select compatible materials; (c) least preferable: to select separable materials.
the use, whenever possible, of recycled materials from old cars under the constraint of functional requirements.

The guidelines for component design are:

- to avoid laminating, foaming and painting when possible; when they are used: to select paints which are compatible with recycling and design laminates with compatible materials;
- to make parts easily separable when this do not interfere with the function;
- to design plastic parts so that they are easily removable;
- to join looms at convenient points to avoid the need for threading back through bulkheads;
- to mark all plastic parts with symbols of the polymer type whenever possible and the function is not impaired.

Parts marking/material coding standards (Parts Marking Stand E-4) provide that all plastics’ parts must be marked according to the standard SAE J1344/ISO 11469 if the size of the part allows; assemblies containing more than one type of materials shall have the identification marking on each part; electronic modules must be marked with their function to allow easy identification (see also Ford 1996).

On the practical side, the above specifications do not eliminate various trade-offs arising in the design process and the latter have to be solved by referring to the criteria of stable performance and quality and, ideally, equal costs (personal communications)

With respect to an ELV management system, Ford is pursuing a number of activities.

In Germany, Ford developed a network of contracted dismantlers, which currently includes 170-180 companies. The technical standards used are those required by German legislation and more stringent than those of the EU Directive proposal. All dismantlers are certified according to Article 4.2 of the German ELV Ordinance, but have been re-audited by Ford to assure compliance with Company standards.

A bumper collection system has been started in 1994 for Germany, Austria and Switzerland that as of mid-1999 has recovered approximately 300.000 bumpers from old cars (Sierra, Escort) for material recycling (personal communications).

In 1998 Ford has started a 'dealer waste collection' program for the collection of all sorts of waste (incl. batteries, tyres, bumpers, used oils, filters, packaging, etc) coming from vehicle repair, maintenance and service for a subsequent recycling or environmentally friendly disposal. Ford also runs a comprehensive re-manufacturing program for selected automotive components (more than 500.000 parts annually).

Since 1991 Ford is operating an experimental dismantling center at Cologne which serves the following purposes:

- development of efficient de-pollution methods
- assessment of most efficient dismantling methods and sequences
- establishment of a reliable data base on material break-down, material compatibility, etc
- identification of parts/components suitable for re-use or material recycling
- provision of expertise data for a vehicle recyclability/recoverability assessment

Ford refers to recyclability categories for classifying all materials, parts and components, to better define recyclability attributes, and for calculation of the vehicle's overall recyclability/recoverability. They provide a common basis for discussions with the supply industry, and help to identify components and parts that aid or impede the recycling process. There are seven recyclability categories ranging from 0 (fully recyclable) to 5 (no known technology for recycling) and 6 (not applicable).

In general, the calculation of the vehicle's recyclability/recoverability poses various difficult issues given its multiple variable interpretations and the lack of calculation standards (personal communications). On the practical side, the most important constraints arise for plastic recycling given the still not developed market and the limited possibility of cascade recycling. The development of a closed loop must be pursued firstly at the local level, given the role of transportation cost for plastic recycling. The price of recycled plastics, however, can be competitive for more expensive plastics because the prevailing cost for recycled is of a fixed-cost type (dismantling, handling, transport, etc.) while price of these virgin plastics fluctuate.

Actions for reducing weight are considered as possibly conflicting with higher recyclability objectives. The US P2000 vehicle, for example, uses aluminium rather than ferrous sheet metal for the uni-body and closures and aluminium and magnesium for a variety of other vehicle sub-systems, thus reducing the overall vehicle weight by 40% as compared to Ford Taurus or Mondeo. Compared to the current production Mondeo, the basic recyclability of a P2000 type Mondeo is about 10% lower given the fact that the easily recyclable metal content (in % of the vehicle weight) is significantly reduced. In general, by extrapolating the 1975-95 trend, Ford expect that recyclability of European cars will decrease gradually - because of light-weighting actions to improve fuel economy and emissions- and so to diverge from mandated recycling targets. The required effort to increase recyclability under the above guidelines is therefore to be measured against unfavourable trends. The average composition of Ford cars is reported in Table 2.2.8.
Table 2.2.8. Average material composition of a Ford car

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage of total weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous metals</td>
<td>72%</td>
</tr>
<tr>
<td>Non-ferrous metals</td>
<td>5%</td>
</tr>
<tr>
<td>Glass</td>
<td>3%</td>
</tr>
<tr>
<td>Tyres/rubber</td>
<td>4%</td>
</tr>
<tr>
<td>Plastics</td>
<td>9%</td>
</tr>
<tr>
<td>Fluids</td>
<td>2%</td>
</tr>
<tr>
<td>Coatings</td>
<td>2%</td>
</tr>
<tr>
<td>Other</td>
<td>3%</td>
</tr>
</tbody>
</table>

Source: Ford Europe (personal communications).

LCA is used at Ford as an internal tool to contribute to material and component selection. The “cradle to grave” analysis is deemed possible only at the level of material/components comparison, e.g. steel Vs aluminium body, and not for the car as a whole given its extreme complexity. A case of LCA developed at Ford is that of 100% battery cases recovery (see Schmidt and Beyer 1999). The case compares different solutions: energy recovery Vs landfilling Vs mechanical recycling. The balances are differently favourable according to the environmental aspect considered and the weight assigned to different objectives (emission, land pollution, etc.). Another case is the comparison of reinforced PP Vs glass fibres. In general, the decision is based on a multicriteria decision matrix with 18 specifications including recycling quotas (targets). The decision process is very complex and on the choice about what (CO2, SOx, etc.) is the priority is made also according to perception of external priority (policy makers, public opinion).

New Ford vehicle models contain between 30 and 50 parts made out of recycled content materials (post-industrial and post-consumer) corresponding to around 15% of the total amount of plastics used in the vehicles. Recycled consumer goods e.g. shredded cotton from jeans is used to make underhood sound-deadening components. Computer housings and telephones are recycled to make instrument cluster housings and radiator grilles; old bumpers are recycled for bumper brackets. Batteries become battery trays or are even 100% recycled into new batteries - as for the UK Fiestas and Escorts. The Ford Charleville plant converted all plastic parts (for heater and A/C system) to contain at least 25% post-consumer recycled materials. For most of the plastic components in Ford vehicles, recycled content materials have been specified and released as an alternative to virgin materials.
II.3. Italy

New car registrations in Italy were 2,374,747 in 1998 (17% of total EU15). The registration of new cars of Italy-based companies (FIAT Group) in EU15 were 1,560,950 (11.2% of total EU15).

The number of ELVs was estimated at 1.1 million units in 1994 and the estimated amount of ASR from ELV was 360,000 tons in the same year (see IPEE 1996). The latter represented, however, an extremely depressed year for the Italian car market. The normal annual flow of ELVs in Italy can be considered around 1.5 million units. The introduction of incentives for scrapping and substituting cars older than 10 years in 1997, created a very large stream of scrapped cars in 1997-98. The latter is estimated at around 2.0 million units in 1997 (of which 1,150,000 with scrapping incentives) and 1.8 million units in 1998 (650,000 with scrapping incentives). The need to comply with the deadlines established by the Commission (December 1999) for the phasing-out of leaded gasoline in Italy (end-2001) will probably cause another wave of ELVs in the next few years, possibly stimulated by incentive schemes (see also Par. I.4.3). The scrapping incentives scheme of the recent past also contributed to decrease the average age of Italian car stock, currently estimated at 14-15 years. Export flows of ELVs to be reused are reported towards Albania and other Eastern European countries as well as North Africa.

II.3.1. ELV regulation developments

Specific provisions for ELV have been introduced in Italy through the Decree No. 22, February 5, 1997, also known as Decreto Ronchi. The latter represents the transposition law of EC Directive 91/156 on waste, Directive 91/689 on hazardous waste and Directive 95/62 on packaging and packaging waste. It was expected long time ago, it was soon updated with the Decree No. 389 of November 8, 1997, followed by other amendments and its implementation requires around 20 specific regulations, possibly followed by other technical regulations, in the various fields of waste management.

Motor vehicles and their parts that reach the end of their useful life are classified as "special waste" together with demolition and agricultural waste as well as others waste streams. The Regional governments are the administrative level responsible for the complex authorisation procedures for disposal/recovery sites and plants.

The article of the Ronchi Decree addressing specifically motor vehicles is the No. 46. The main provisions can be summarised as follows:

47 The analysis is also based on direct interviews with Rossana Serra (FIAT Auto), Paolo Cortesi (ENICHEM), Eugenio Turchetti and William Bandinelli (ASSOFERMET), Mr Zoccolan (ASSOMET), Giampaolo Giuliani (Pirelli), Gian Clemente Mantegazza (Eco.Pne.Us.), and phone interviews with Rosanna Laraia (ANPA), and Vincenza Lechiancole (ADA).
The owner of a vehicle willing to dismantle it, must deliver the vehicle to a center for collection/depollution/recovery/dismantling which is authorised according to the procedures established in Art. 27, and 28 of the Decree itself. The owner can alternatively deliver the motor vehicle to a dealer of the car/vehicle maker and the latter will deliver to the authorised dismantler. The economic aspects of the take back transaction are not specified. In practice, the transaction take place between the last owner and the dealer/dismantlers and it occurs at market conditions except for the dismantlers associated to the FARE system (see below) that pay the last owner a small lump sum.

The dismantler or the dealer must give the owner a certificate specifying the features of the vehicle. The dismantler/dealer is responsible for deregistration from the PRA (Pubblico Registro Automobilistico) which is the body registering all the vehicles circulating in the country.

Since June 30, 1998 only the dealer/dismantler is allowed to make the deregistration and must make it within 60 days from the receipt of the vehicle. The dismantler/dealer cannot ask commissions for the administrative costs of deregistration.

The certificate makes the last owner free from any legal obligation related to the vehicle.

Dismantlers cannot dismantle before the above administrative procedures have been fulfilled.

The trade of spare parts deriving from dismantling is allowed, except in the case it involves problems for safety. Parts having problems with safety must be delivered to auto repair facilities that have to fulfil other procedures for getting the required degree of safety.

Within six months from the entry into force of the (updated) Ronchi Decree, the Ministry of Environment and the Ministry of Industry together should have had to produce the technical regulations regarding the features of dismantling facilities and depolluting procedures as well as spare parts having safety problems.

The above-mentioned technical regulations on dismantling sites and activities have been prepared by the National Environmental Agency (ANPA - Agenzia Nazionale per la Protezione dell'Ambiente), and delivered to the Ministry of the Environment in 1999. The draft regulation (not publicly available) is not different form the list of requirements enclosed in the EU Directive proposal, although it is more detailed. It includes, among the other provisions, the obligation of dismantling of tyres, catalytic converters, battery, fuel, gas tanks, operating oils, brake and refrigerating fluids, air bags and pretensioners. Car producers and importers must supply dismantling manuals on circulating models. The introduction of the technical regulation are currently in stand-by, waiting for the EU Directive and the technical provisions there enclosed (personal communications).

The present situation is causing uncertainty on investments by dismantlers given that they do not know exactly the technical requirements for complying with the regulation deriving from Ronchi Decree, and they hope for a rapid conclusion of the EU Directive approval (personal communications).
The implementation of Ronchi Decree, together with other recent regulations on waste management, are creating various technical uncertainties on sectors related to ELV treatment. The Ministerial Decree No. 503/97 on emissions from waste incineration plants introduced more severe limits, exclude tyres and ASR from the area of "simplified procedures" established in 1995, discourages the energy recovery of these and other waste streams in isolation while stimulating their recovery in combination with household waste as Refuse-Derived-Fuel. The decree created a displacement of dismantling and scarp trade as well as some recovery activities, as in the case of the recovery of tyres in the cement industry. In 1997, the cement industry treated 30,000 tons of used tyres compared to usual flows of 100,000 tons (corresponding to one third of the estimated 300,000 total) due to lacking authorisation in the transition period (personal communications). A significant project on RDF for tyres is being developed by the Pirelli Group, based on own patents and technologies, which would be able to treat almost half of the annual flow of used tyres in Italy. Only 10% of total used-tyres annual flow in Italy, however, is represented by tyres from ELV (personal communications).

Well established recycling activities exist for ferrous and non-ferrous metals from ELV, also due to a very large steel production from scarp in Italian mini-mills and the significant secondary production of non-ferrous metals that make Italy a significant metal scrap importer. The developments of other recycling streams occurred in connection with the FARE initiative.

The industrial actors involved in ELV are, further to FIAT, around 4,500 dismantlers, 300 crushers (trading and preparation of wrecks), and 19 shredders (Table II.3.1)

| Table II.3.1. Operators in the downstream part of ELV chain in Italy |
|---|---|---|
| | Dismantlers | Crushers | Shredders |
| Number | 4,500 (1,500 authorised) | 300 | 19 |
| Average productivity | 10 car/day | 100 car/day | 500 car/day |
| Main business | Trading of used spare parts | Trading of iron scraps | Selling of metal to recycle to steel industry |

Source: Serra and Di Carlo (1999).

**II.3.2. The FIAT's F.A.RE system**

**Organisation**
The FARE system (Fiat Auto REcycling) is active from 1992. It is based on the integration of different activities with the main focus on dismantling and the creation of loops for recycled materials (including “cascade recycling”) as well as ASR energy recovery. The principles underlying the initiative are those of shared responsibility among the participants and free market. The stated targets are the recycling of 85% of car weight by 2002 and 95% by 2010. The system was initiated with the aim of demonstrating the possibility to avoid European detailed regulation and the feasibility of a voluntary agreement (personal communications).
The management of the system is based on a set of framework agreements between FIAT and the other participant association/companies combined with bilateral specific contracts between the participants in the recovery/recycling chain. The network relationships are depicted in Figure II.3.1 (see Serra and Di Carlo 1999; Di Carlo, Giolitti and Serra 1998).

Figure II.3.1. The organisation of the FARE system

A framework agreement with ADA, the association of Italian dismantlers, was signed. Starting from few (six) dismantlers involved at the beginning, the participating dismantlers became 312 in all the Italian regions in 1998 (see Figure II.3.2). The dismantling activities include the depollution through the extraction of batteries, oil, operating fluids, and the dismantling of spare parts, bumpers, glass, seats, catalytic converters. Major economic returns for dismantlers are from the recovery of spare parts.
The subsequent operations include shredding, with the separation of steel and non-ferrous metals, energy recovery from fluff, mechanical recycling of parts and materials, cascade recycling in new FIAT cars. The activities are regulated by framework agreements between FIAT and specific companies while the latter have bilateral commercial contracts with individual dismantlers in the network.

The recovery/recycling circuit for bumpers is based on an agreement with MONTELL (preparation and transport) and Politec which perform the recycling operations (cleaning, grinding, extrusion and granulation). Politec plant has a capacity of 1 ton/hour. The recycled plastic is then used by a component producing company for producing air ducts to be used in new FIAT cars. The third cycle in the cascade-recycling sequence is the use of recycled plastic for carpets in new cars with the residual used in energy recovery processes. The preference has been for applications not requiring complex regeneration processes, as paint removal.

The dismantled seat foam is treated by a company (Strapazzini) which recycle them into under-carpets used in new cars. Glass is recycled by Emiliana Rottami which then supplies big glass producers, as Saint Gobain, for the production of bottles and cans. A good market for recycled glass exists in Italy. The recovery and recycling of catalytic converters is organised in cooperation with Rhone Poulenc and precious metals are recovered. For the shredding operations an agreement with Falck was established and the same applies to the use of fluff for pre-treatment of steel.
The FARE system includes the agreement with Renault, BMW and Rover (see the analyses of France and Germany) for the integration of the respective dismantling networks though the reciprocal acceptance of ELV of the four brands. According to the number of ELV collected and treated, the agreement is fully operational in Italy and it is subject to positive developments in France and Germany, given the accelerated creation of the authorised dismantling networks by both the French and German partners. The agreement is considered to have produced very useful exchange of information and experiences between the partners (personal communications).

FARE it part of a wider cooperation agreement (“Protocollo di intesa”) between FIAT and the Italian Ministry of the Environment signed in 1997. The cooperation agreement also includes commitments to reduce fuel consumption and emissions of new models, the production of car with minimum environmental impact, and programmes for car-pooling. However, FARE is not supported by public incentives and is completely self-sustained from the financial point of view. The only commitment by the Ministry is to supply in the next future the legislation framework for dismantling, recycling and energy recovery for ELV, also in connection with the new Italian legislation on waste and the EU Directive on ELV (see above).

A national level voluntary agreement, based on the FARE experience is under discussion under the auspices of the Ministry of the Environment, and it would involve all the main actors in the ELV activities (see Di Carlo et al. 1998; personal communications). Various difficulties, however, are still slowing down the process, e.g. the difficulties on finding a full agreement on roles and responsibilities and, not least, the expected approval of the EU Directive. As a consequence of the EU Directive, in fact, the possibility to have a national voluntary agreement based on shared responsibility before the transposition of the Directive is weakened. The working of FARE system is considered to be possibly damaged by free take back provisions. The FARE system will go on in any case and FIAT will promote an agreement not based on incentives (personal communications).

Results
From the beginning of the FARE system to December 1997, more than 771,000 cars were treated (around 200,000 in 1997). The introduction of the Italian incentive scheme for substitution of cars older than 10 years (“rottamazione”) created a sharp increase in the number of cars treated that reached the number of almost 800,000 in 1998 alone (see Figure II.3.3).
The total amount of non-metallic materials recovered/recycled from the 1,140,000 cars dismantled from the beginning of the system are summarised in Table II.3.2.

The rate of recovery achieved is calculated at 82% of car weight including energy recovery. A complete recovery of tyres could be enough to reach 85%. The extension of the system at a full national scale could create effects of different sign on the scheme because the greater complexity of management would be accompanied by the advantages of a greater scale of operations. The achievement of 82% recovery rate is considered to be at zero cost, but to go beyond 82% is considered costly and implies hard work on network coordination, car conception, and design (personal communications).

Table II.3.2. Dismantled materials from the FARE system 1992-98

<table>
<thead>
<tr>
<th>Dismantled materials</th>
<th>Re-use/recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>19,210 tons</td>
</tr>
<tr>
<td></td>
<td>Bottles</td>
</tr>
<tr>
<td>Bumpers</td>
<td>5,424 tons</td>
</tr>
<tr>
<td></td>
<td>Air ducts and parts of interior finish of new FIAT models</td>
</tr>
<tr>
<td>Seat foam</td>
<td>6,554 tons</td>
</tr>
<tr>
<td></td>
<td>Insulating devices in new cars and other non-car applications</td>
</tr>
<tr>
<td>Total</td>
<td>31,188 tons</td>
</tr>
<tr>
<td>Catalytic converters</td>
<td>4,000 units since 1995</td>
</tr>
</tbody>
</table>

Source: Serra and Di Carlo (1999).
Difficulties arise in the attempt for more extensive developments of plastic recycling markets, and this is also a key point of the DFD/DFR activity of FIAT.

Plastic recycling in Italy occurs mostly on “new scrap” streams deriving from production processes and not from post-consumer flows. The only one company actually dealing with plastics from end-of-life products is MONTELL. The recovery of bumpers is technically good but it is expensive. The same applies to other materials streams (glass, seats foam) while other parts, e.g. tanks, combine high costs and technical problems.

During the 1990s, FIAT participated to RECAP, the Eureka project on plastic recycling at the European scale, together with other partners, including ENICHEM and Peugeot (see RECAP 1998, the case of PSA, and Part III). Dismantable plastic components are estimated at 45 % of weight but available applications can absorb only 15 kg, and the scale of activity is too low to be profitable. For example, the total foams dismantled from ELV in Europe would be 12,000 tons that correspond to the capacity of 3/4 plants only in Europe. For dashboards, one plant only in Europe would be enough and this would create critical logistic problems.

FIAT is pursuing extensive developments in DFD and DFR. In general, the concern about dismantability and recyclability is increasingly penetrating design and car making processes at all level in the company, together with environmental strategy in material choice based on LCA.

There is a progressive reduction of plastics number and mixes in most recent car models. The FIAT Tipo contained 14 families of plastics while Bravo/a only 10 plastics families (Table II.3.3).

Other criteria of DFD/DFR already applied include increased dismantability, also based on internal experiences in pilot dismantling facilities at FIAT, the integration of components made of the same material, the preference for mono-material components instead to multi-materials components, and the adoption of marking systems and dismantling manuals. LCA is applied to materials and components. Environmental requirements and preference for more recyclable materials are imposed to suppliers (personal communications).
Table II.3.3. Polymer families in different FIAT models
(percent of total plastic weight)

<table>
<thead>
<tr>
<th>Polymers</th>
<th>FIAT Tipo</th>
<th>FIAT Bravo/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyurethane</td>
<td>14%</td>
<td>10%</td>
</tr>
<tr>
<td>PMMA</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Styrene</td>
<td>4.5%</td>
<td>-</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>1%</td>
<td>-</td>
</tr>
<tr>
<td>Polyoxysphenile</td>
<td>3%</td>
<td>-</td>
</tr>
<tr>
<td>Polyamide</td>
<td>6.6%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Phenolic</td>
<td>0.5%</td>
<td>-</td>
</tr>
<tr>
<td>Polyester BMC</td>
<td>3%</td>
<td>-</td>
</tr>
<tr>
<td>Composites</td>
<td>7%</td>
<td>5%</td>
</tr>
<tr>
<td>Thermoplastic polyester</td>
<td>1.5%</td>
<td>3.5%</td>
</tr>
<tr>
<td>PVC</td>
<td>7%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Acetal resins</td>
<td>2%</td>
<td>-</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>10%</td>
<td>13.5%</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>36%</td>
<td>49%</td>
</tr>
<tr>
<td>Others</td>
<td>3%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

Source: adapted from Di Carlo et al. (1998)

The possibility of future phasing-out of some materials is taken into account in design, as in the case of PVC.

Recyclability coefficients are elaborated also in cooperation with BMW. They are not publicly available but include dismantling times and recovery costs. It is greatly difficult to standardise them, given the great variability of the different conditions. This suggests that it could be difficult to arrive at common European standards, and the achievement of shared and sound criteria is highly problematic (personal communications).
II.4. The Netherlands

In 1998, new car registrations in the Netherlands were 543,067 (3.9% of total EU15). With the exception of a Volvo-Mitsubishi plant, the car industry in the Netherlands is represented by the importers that are generally part of European, American and Japanese automobile groups.

The number of ELV is estimated at 270,000 in 1997 and ASR is estimated at 33,000 tons in the same year (ARN 1998). Significant flows of ELV exports as second-hand cars in Eastern European countries are estimated by non-official sources.

II.4.1. The ARN system

The Dutch policy on ELV started from a series of structured and finalised discussion among the actors involved that took place between late-1980s and early-1990s. They resulted in the action programme of 1992 and the subsequent development of an original policy scheme — based on financial instruments to support the development of recycling activities— which is different from the approaches taken in the other European countries (with the partial exception of Sweden).

In October 1993, with the approval of the Ministry of Housing, Spatial Planning and the Environment, the Auto Recycling Foundation was created to which the industries involved in ELV participate (RAI: car manufacturers and importers; BOVAG: garages; FOCWA: damage repair companies; STIBA: car dismantlers; SVN: shredder companies). The foundation created an independent company, the Auto Recycling Netherlands BV (ARN), that has the task of managing the system for ELV recovery and recycling. The system is aimed at achieving a recycling target of 86% of the car weight by 2000 and it is based on the creation of a cooperation network between the car industry, the dismantlers and the recyclers.

The instrument for funding the system is a “disposal fee” paid by the first owner on new cars registered in the Netherlands. The fees are managed by ARN and used to pay “recycling premiums” to dismantlers, transporters and recyclers for the extra-costs incurred in their activities (see ARN 1997 and 1998). The fee, initially established at a fixed level of 250 NGL per car, is enshrined in the Dutch Environmental Management Act and has been declared legally binding by the Ministry of Housing, Spatial Planning and the Environment for the period January 1, 1995 to December 31, 1997 inclusive. The fee has been reduced to 150 NGL (68.2 Euros) as from January 1, 1998 due to the decreasing costs of the operations to be financed and has been declared binding for the following three years.

48 The analysis is also based on the interview with G. Schaap and J.N.M. Kuipers (ARN BV).
49 The ARN is owned at 100% by the Foundation. From 1997, the SVN does no more exist as association and the remaining shareholders are RAI, BOVAG, FOCWA and STIBA.
50 The fee is levied on purchase price of a new car license issued for a vehicle with four or more wheels and an empty weight and loading capacity of maximum 3,500 kg.
The establishment of ARN and the fee-based scheme was instrumental to anticipate likely policy developments based on detailed regulation of ELV in the Netherlands, including the possibility of a ban on ASR landfilling (personal communications).

Only companies contracted by ARN carry out dismantling and recycling activities. Licensed car dismantlers members of ARN are contractually obliged to dismantle a specific list of materials and parts. The collectors and recyclers contracted by ARN are bound to accept the dismantled materials and submit it to high-grade recycling. The ARN will pay a financial premium the dismantlers and recyclers on the basis of weight of materials that are administratively verified to be treated. The users of recycled materials as well as shredders are not included into the scheme. Car importers are relatively passive in the working of the scheme.

Dismantlers are subject to certification procedure. The criteria were made more stringent in 1997. The recyclers are subject to environmental standard BS 7750. The latter is very stringent, more than they are able to reach, and the possibility of alternative standards is currently envisaged.

The companies registered with ARN can process only materials that can be usefully recycled or represent an environmental burden. The choices on the processing of dismantled materials, that arrive to recyclers through the collectors/transporters, is based on the ‘Lansink Ladder’ hierarchy, i.e. prevention, product reuse, reuse of constituents materials, incineration with energy recovery, incineration, landfilling. Every year the recycling companies applies for treating a certain quantities of materials though tenders and ARN guaranties a certain amount of materials to tenders’ winners.

ARN has a pivotal role in the whole scheme. ARN participates in contracts between dismantlers and recyclers; it plans the relationships in the system by allocating quantities among recyclers; it establishes a price system for them and controls the distribution of premiums starting from tender procedures. Different premiums are established for each activity and materials and they are differentiated company by company according to their bids in the tender procedure. ARN also estimates the amount of the required disposal fee through a forecasting system on costs which includes calculations about the future flows of ELV (ARN 1998).

The disposal fee implies no payment by the last car-owner, and dismantlers take back the car free if they are in the ARN system. The last owner receives a certificate of disposal and the relief of ownership tax is linked to the certificate. Although it makes last-owner free from payment, the system implies a certain and fixed payment by the first owner (as opposed to an uncertain and variable payment by the last owner as FTB). According to ARN, the disposal fee is preferable because it is more transparent and it is better to have the final owner not involved. A fee on new cars can reduce the risk that the final owner does not deliver the ELV, while a FTB applied to last owner cannot eliminate the risk of non-delivery if its level is not satisfactory. In addition, a disposal fee does not eliminate the possibility for the last owner to receive a payment if the car is in good state (personal communications). It is immediately apparent, on the other hand, that a fixed fee is regressive and creates a disadvantage on small car buyers, and thus presumably on lower-income consumers. The choice of an instrument applied at the beginning of the ELV chain, as opposed to instruments applied to the last-owner, illustrates the great significance of the level to which the economic instruments is imposed. The most debated
issue about the Dutch approach, however, is the use of the funds raised with the fee for financing dismantlers and shredders. The “infant industry argument” implicit in the scheme, i.e. the need of incentives to create the start up of new recycling activities that might become self-sustained, as suggested by the objective of a zero fee in the long run, is opposed by most European car makers, and in particular by German carmakers (see Schenk 1999 and Part III for a discussion).

II.4.2. Results

The number of dismantlers in the ARN system grew from 266 in 1996 to 278 in 1997 that represent 30.6% of the total 907 dismantlers licensed in the Netherlands. The number was stable in 1998. The number of car wrecks processed within the system in 1997 was 237,266 that represent around 90% of the total number of ELV. The figure represent an increase of 13% compared to 1996, which already marked a growth of 63% over 1995. The estimates for 1998 show a slight decrease (ARN 1999). The latter is due to a number of total ELV in the Netherlands (270,000) lower than expected (300,000). One reason for this is that the average age of ELV in increasing more than expected, from 13.6 years in 1996 to 13.8 years in 1997. Other reasons are indicated in changes of import and export flows of cars which, however, seems to be more significant for future availability of ELVs. The forecasting of future number of ELV to be processed is an important element of ARN operations that make the system a wholly-planned one (see ARN 1998). The above figure confirm a longer-term trend of strong and increasing market share of dismantlers participating in the ARN system at the expenses of dismantles outside the system (ARN 1999).

The quantities of materials dismantled and recycled by ARN companies in 1997 is in Table II.4.1.

An average 89.2 kg of materials and 6.8 fluids per car were processed (Table II.4.2). In addition to the listed materials, also LPG tanks were dismantled and recycled in 1997. The list of materials is gradually expanding reaching the number of 19 categories in 1998 (ARN 1999).
Table II.4.1 Total quantities of materials recycled in 1997 by ARN companies
(tons or 000 litres; rounded figures)

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity recycled</th>
<th>Quantity in the pipelines*</th>
<th>Total pipeline + total recycled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries</td>
<td>2,779</td>
<td>658</td>
<td>3,454</td>
</tr>
<tr>
<td>Rear lamps</td>
<td>53</td>
<td>154</td>
<td>207</td>
</tr>
<tr>
<td>Tyres</td>
<td>6,621</td>
<td>2,063</td>
<td>8,684</td>
</tr>
<tr>
<td>Inner tubes</td>
<td>76</td>
<td>92,6</td>
<td>169</td>
</tr>
<tr>
<td>Bumpers</td>
<td>755</td>
<td>478</td>
<td>1,232</td>
</tr>
<tr>
<td>Glass</td>
<td>5,539</td>
<td>2,942</td>
<td>8,482</td>
</tr>
<tr>
<td>Safety belts</td>
<td>48</td>
<td>74</td>
<td>121</td>
</tr>
<tr>
<td>Grilles</td>
<td>30</td>
<td>80</td>
<td>110</td>
</tr>
<tr>
<td>Coconut fibres</td>
<td>146</td>
<td>89</td>
<td>235</td>
</tr>
<tr>
<td>PUR foam</td>
<td>1,361</td>
<td>650</td>
<td>2,011</td>
</tr>
<tr>
<td>Brake fluids</td>
<td>38</td>
<td>62</td>
<td>100</td>
</tr>
<tr>
<td>Rubber strips</td>
<td>1,880</td>
<td>780</td>
<td>2,660</td>
</tr>
<tr>
<td>Windscreen fluids</td>
<td>159</td>
<td>43</td>
<td>202</td>
</tr>
<tr>
<td>Hub caps</td>
<td>19</td>
<td>56</td>
<td>75</td>
</tr>
<tr>
<td><strong>Total tons</strong></td>
<td>19,525</td>
<td>8,221</td>
<td>27,746</td>
</tr>
<tr>
<td>Coolant</td>
<td>605</td>
<td>232</td>
<td>837</td>
</tr>
<tr>
<td>Oil</td>
<td>1,043</td>
<td>245</td>
<td>1,288</td>
</tr>
<tr>
<td><strong>Total litres</strong></td>
<td>1,648</td>
<td>477</td>
<td>2,126</td>
</tr>
</tbody>
</table>

* Materials under process or storage by dismantlers and collectors.

Source: adapted from ARN (1998).

Most of the materials (batteries, oil, coolant, brake fluid, LPG tanks, tyres) are treated by known recycling technologies and, when different recycling techniques are available, the ARN is pushing for the most efficient one. Used tyres are also exported. For rubber strips a high grade recycling has been organised but recently a good proportion has been incinerated with energy recovery. The recycling of PP and PC from bumpers give rise to plastics used in the car industry. The same applies to PUR foam. ARN does not have, however, a monitoring system for final uses of recycled materials arising from the system (personal communications).

In cooperation with recyclers, ARN is doing major efforts in R&D and in developing recycling technologies and markets in different directions. One area is the best way of tackling the changing material composition of cars getting the stage of ELV, i.e. containing more polymers and new parts compared to the past. A second area is the shift of tyres recovery from incineration to recycling as a raw material for high-quality rubber products. A third area is the
recycling of ASR. Between 1997 and 1998, legislation first leading at the prohibition of ASR dumping and then to technical problems in ASR incineration in waste incineration plants, created the opportunity for a joint initiative between ARN and the Metal Recycling Federation for promoting alternative approaches to ASR recovery, in particular through separation.

Table II.4.2. Materials and quantities recycled per wreck in 1997

<table>
<thead>
<tr>
<th>Quantity per wreck</th>
<th>kg/ltr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mat. from the engine area</strong></td>
<td></td>
</tr>
<tr>
<td>Batteries</td>
<td>13.6</td>
</tr>
<tr>
<td>Used oil</td>
<td>4.2 ltr</td>
</tr>
<tr>
<td>Brake fluid</td>
<td>0.3</td>
</tr>
<tr>
<td>Coolant</td>
<td>2.6 ltr</td>
</tr>
<tr>
<td>Windscreen washer fluid</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>External materials</strong></td>
<td></td>
</tr>
<tr>
<td>Tyres</td>
<td>27.4</td>
</tr>
<tr>
<td>Inner tubes</td>
<td>0.5</td>
</tr>
<tr>
<td>Glass</td>
<td>25.4</td>
</tr>
<tr>
<td>Rubber strips</td>
<td>7.7</td>
</tr>
<tr>
<td>Plastic bumpers (PP and PC)</td>
<td>3.1</td>
</tr>
<tr>
<td>Grilles (ABS)</td>
<td>0.8</td>
</tr>
<tr>
<td>Rear lamps</td>
<td>1.4</td>
</tr>
<tr>
<td>Hub caps</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Interior materials</strong></td>
<td></td>
</tr>
<tr>
<td>PUR foam</td>
<td>6.3</td>
</tr>
<tr>
<td>Coconut fibre</td>
<td>0.7</td>
</tr>
<tr>
<td>Safety belts</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>89.2 kg + 6.8 ltr</td>
</tr>
</tbody>
</table>


In 1997, the official recycling target of 86% of car recycling has been achieved (Table II.4.3). The calculation is based on a combination of assumption, externally supplied figures and actual measurement on materials. The development of certification system after 1995 made possible to know the weight and the number of each car registered in the Netherlands. The average car weight in 1997 was 875 kg. ARN does not deal directly with metals and thus the metal content of cars has been calculated from data available in the literature and fields experiences of 1996.
It resulted 75% of total weight. While the ARN materials are known and precise figure are available, the remaining fraction after metal and materials extraction, i.e. at the post-shredding phase, is not known and it is estimated as a residual (ARN 1998). At this stage, a rate of recovery of 86% is considered the maximum attainable (personal communications). Although with a great uncertainty, the expectation of continuing changes of car materials leads to the forecasts that disassembling in 2003 (cars produced in 1990) will attain lower recycling rates (ARN 1996).

Table II.4.3. Recycling rates achieved in 1997

<table>
<thead>
<tr>
<th>Average wreck weight</th>
<th>875 kg</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARN materials 1997</td>
<td>96 kg</td>
<td>11%</td>
</tr>
<tr>
<td>Metals (assumed)</td>
<td>656 kg</td>
<td>75%</td>
</tr>
<tr>
<td>Recycling</td>
<td>752 kg</td>
<td>86%</td>
</tr>
<tr>
<td>Remaining fraction</td>
<td>123 kg</td>
<td>14%</td>
</tr>
</tbody>
</table>

Source: ARN (1998)

Some problems arose with the shredders for alleged adverse impacts caused by the ARN system (see ARN 1996). The possible competition effects of the scheme are also questioned, although they can be little significant at the international level given the non-discrimination between domestically produced and imported cars (see OECD 1996). In this regard, however, part of the opposition by carmakers to the Dutch approach is based on the alleged distorting impact that the latter can have on European markets for recycled materials (see Part III).

II.4.3. Financial flows

In 1997, car sales in the Netherlands were higher than expected and a total of 624,477 cars were registered. The associated flow of disposal fees (250 NGL per car) to Auto Recycling Foundation were 127 million NGL after VAT. The amount of recycling costs, i.e. the recycling premiums paid, were 55 million NGL. Other major cost items were monitoring costs (about 2.3 million NGL), pilot recycling and research (1.5 million NGL) and general costs. The substantial financial surplus of ARN operations (71 million NGL) was added to the ARN fund (Table II.4.4)

It is expected that the number of cars to be dismantled will be increasing in the next few years and their composition will increase per se the cost of recycling. The availability of a substantial financial fund to finance the operations is thus in line with the calculated requirements up to the end of 2000. If the fund will be still rising, the surplus will be devoted to decrease the disposal fee.
Table II.4.4 The flows and stock of the ARN fund (million NGL)

<table>
<thead>
<tr>
<th>Year</th>
<th>Stock and additions to the ARN fund</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>84</td>
</tr>
<tr>
<td>1996</td>
<td>52</td>
</tr>
<tr>
<td>1997</td>
<td>71</td>
</tr>
<tr>
<td>Total stock</td>
<td>207</td>
</tr>
</tbody>
</table>

Source: ARN (1998)

II.4.4. Prospects

The recycling policy guidelines established by ARN are different between the period 1998-2000 and the period after 2000 (ARN 1998).

The main lines of the system will not be changed in the short term (up to 2000) and the main objectives of 86% recycling in 2000 will be maintained. Leaving aside the already established decrease of the disposal fee, the fee-based system will not be changed and the fee will remain with no differentiation by type of car, as it is at present. The possible method for differentiating according to recyclability degree is considered unreliable.

Further progresses are pursued for increasing the rate of car processed by ARN and the upgrading the ARN companies. The first progress is hindered by over-capacity in dismantling. Almost 30,000 Dutch cars are still dismantled by the more than 500 small dismantling companies not belonging to the ARN system. They often do not fulfil the environmental requirements and create unfair competition to the companies in ARN system. Within the latter, the possibility of frauds or illegal use of premiums has to be prevented by reinforcing the system of controls. From 1998, in addition to usual accounting reporting by companies a mechanism of annual auditing will be introduced also on environmental aspects and the movement of goods.

For recycling policy after 2000, some new directions are envisaged.

It is likely that the target of 95% recycling proposed by the European Directive will be adopted.

One area of major emphasis will be the increase up to 100% (from the already very high level of 90%) of the number of Dutch ELV treated by the companies in the ARN system. The latter have more than sufficient capacity to treat all the ELV and the financial fund available is enough for the financing of the additional operations.

A second priority is to create the condition for a further reduction of disposal fee. The instrument is the reduction of costs of dismantling/recycling and increase in the proceeds from the material recycled. The first aim can be achieved by upgrading the techniques used by dismantlers and recyclers while the second one through the refinement of market penetration instruments, e.g. by moving from bulk products to high-quality intermediate or end products from recycled materials.
A third area of emphasis is the search for additional forms of treatment of ELV waste. The EU Directive is considered more demanding than the objective of 86% by 2000 and it is necessary to work on technologies able to make the EU target achievable. Given the complexity of some components and the difficulties in its mechanical recycling, additional alternative recycling systems, such as the processing of shredder waste will be necessary. Incineration with energy recovery, in accordance with the situation of other European countries, “have to be regarded as one of the methods of recycling, to be applied only under certain conditions” (ARN 1998).

A fourth priority is to make the car dismantling industry more professional. Despite the ongoing change in the level of dismantlers, more is to be done for reaching a better economic equilibrium of activities, in particular though the search for more advanced links with the rest of the car industry. One possibility is that of developing more the market for spare parts in cooperation with car dealers. This market is not under the control of ARN system. An example is the agreement between Mercedes-Benz Nederland and a dismantling company activated in 1997 (ARN 1998).

The fifth priority is the development of DFR. According to ARN, car producers have done still limited progresses in DFR, and increasing research efforts are needed. The experience by ARN itself can supply useful information in this field. However, the attempt to involve carmakers to show the results on recycling innovations, e.g. recycling of PUR foam with metal strips, did not receive attention. Some information has been supplied to carmakers for lead, coolant and other materials. Marking systems in many cases are not well working (personal communications).

In the next future, Dutch government will work on a legal framework for ELV but assured to maintain the ARN system. The latter seems not to show operational contradictions with other waste regulations, e.g. tyres.

At the European level, ARN claims that the EU Directive proposal contains all the essential constituent elements of the Dutch system, and therefore the ARN looks at the Directive as well balanced, capable of confirming the correctness of the Dutch system. The implied harmonisation process is considered to be useful (ARN 1998).
II.5. Sweden

New car registrations in Sweden in 1998 were 253,430 (1.8% of total EU15). The registration of new cars produced by Sweden-based manufacturers (Volvo and Saab) in the EU15 were 316,202 in 1998 (2.3% of total EU15). Almost 86% of new passenger cars and 96% of trucks produced in Sweden were exported in 1998 generating a trade surplus of 39 billion SEK. Cars represent 14% of total goods exported by Sweden.

The estimated number of scrapped cars, as calculated on new registration less net increase in car stock, was 164,000 in 1998, while the number of actually scrapped cars is estimated at 143,576 units in the same year (BIL 1998 and personal communications). The amount of ASR from ELV can be estimated at around 36,000 tons in 1997. The Swedish car stock is considered to be old compared to other countries, with 55% of the car fleet 10 years old or older. The probable lifetime of a passenger car in Sweden is estimated at 17 years (BIL 1998).

II.5.1. The ELV regulation process

A car scrapping regulation is in force in Sweden since 1975. It includes a system of dismantlers authorisation, certificates of destruction and a mechanism of scrapping fees and refunds. The latter is based on the provision that the first car owner pays a scrapping fee to a publicly-managed fund. The revenue is then distributed in the form of premiums to both the final car owner when delivers to authorised dismantlers in exchange of the certificate, and to dismantlers themselves in way similar to the Dutch scheme.

The introduction of the system was caused by the great number of car abandoned in Sweden. Its working is considered good and helped to increase the rate of delivery. Differently from other countries, Sweden does not have a system of taxes for non-deregistered cars. The levels of scrapping fees, scrapping premiums and fees on lead batteries, introduced in 1991, are presented in Table II.5.1. The amount of the Swedish scrapping fund is recovering during the last few years due to the increase of scrapping fees and it is expected to be around 800 million SEK at end of 1999.

During the 1990s, a series of conflicting proposals on the regulations and management of ELV where produced, on the one hand, by industries and, on the other hand, by the Government.

51 The analysis is also based on the interviews with Karin Kvist (BIL The Association of Swedish Automobile Manufacturers and Wholesalers), Ulf J-Liljenroth (Volvo), Bo Swaner (Saab).
Table II.5.1. Scrapping fee, scrapping premium and fee on lead batteries in Sweden, 1975-1998 (in SEK)

<table>
<thead>
<tr>
<th>Time</th>
<th>Scapping fee</th>
<th>Time</th>
<th>Scrapping premium</th>
<th>Time</th>
<th>Fee on lead batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1.1975</td>
<td>250</td>
<td>1.1.1976</td>
<td>300</td>
<td>1.1.1991</td>
<td>32</td>
</tr>
<tr>
<td>1.7.1988</td>
<td>300</td>
<td>1.4.1988</td>
<td>500</td>
<td>1.1.1993</td>
<td>40</td>
</tr>
<tr>
<td>1.1.1992</td>
<td>850</td>
<td>1.1.1992</td>
<td>500/1,500*</td>
<td>Since 1.1.99</td>
<td>30</td>
</tr>
<tr>
<td>1.11.1993</td>
<td>1,300</td>
<td>1.1.1994</td>
<td>500/1,500*</td>
<td>Since 1.1.1998</td>
<td>500</td>
</tr>
<tr>
<td>Since 1.1.1998</td>
<td>700</td>
<td>Since 1.1.1998</td>
<td>500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The higher premium level is for cars approved at the annual vehicle inspection within a specified number of months before scrapping.

Source: adapted from BIL (1998).

In 1993, the Ecocycle Bill entrusted the Ecocycle Commission to define the terms of a producer responsibility system for ELV, including quantity targets on recovery/recycling, specific technical regulations and a free take back system (see IPEE 1996). In 1994-95, car producers proposed to the Ecocycle Commission a voluntary scheme for produced responsibility based on the cooperative participation of all the industries involved and the connection with the proposal of the ELV Project Group adapted to the Swedish situation (see Kvist, Hernborg and Liljenroth 1997). The Ecocycle Commission responded with a proposal based on different principles and approaches, including detailed regulations on the main aspects of ELV management. Eight professional associations and companies with interest in car recycling responded by signing an undertaking of responsibility based on the car manufacturers proposal.

The opposition by the car industry to the proposed law and ordinance was very strong (see BIL 1995). The disagreement by industry was on many points, and in particular:

- on the specific features given by the Ecocycle Commission proposal to the producer responsibility principle;
- on the fact that the Swedish Ecocycle Bill gives priority to voluntary undertakings over regulatory solutions;
- on the financial provisions that were "retroactive" for vehicles already in the market; the financial aspects were, on the other hand, the subject of a proposal by the car industry of directly managing the Swedish fund system;
- on the ground of targets that were more stringent than those proposed at that time at the EU level; they included a maximum weight allowed for disposal and a strong limitation of ASR energy recovery possibility.

The only point of agreement was on the need of more stringent regulations on dismantling.

A Government bill containing a proposal for producer responsibility was accepted by the Parliament in June 1996 (Swedish Government 1996). The main points of the ordinance are the following:
- manufacturers and importers of cars shall accept vehicles (not exceeding 3,500 kg) put on the market by the specific producer which are delivered for scrapping;
- cars sold and registered after the producer responsibility’s entry into force must be taken back without costs for the last owner with some established exceptions (e.g. if some valuable parts are lacking or the car is equipped with many parts from other producers);
- the producers shall provide a suitable network of sites for the hand-over of the ELVs;
- the producer will ensure that the car is treated in an environmentally sound way;
- the system of scrapping fees and premiums will continue for the existing fleet;
- car producers shall provide information about the materials in the car and the hazardous substances;
- target for recovery are established at 85% of car weight (in “running order”) by reuse, recycling or energy recovery by 2002, a minimum of 95% recovery in the same forms is required by 2015;
- producers shall have to report on the achievements to the Swedish EPA.

The “Ordinance on Producer Responsibility for Vehicles”, which is based on the above provisions, was issued in October 1997 and entered into force on January 1, 1998. At the same time, the earlier car scrapping legislation of 1975 and the associated provisions remain into force.

The final result seems to be a compromise between regulation and freedom for car producer for arranging the take-back and recovery system (Kvist, Hernborg and Liljenroth 1997). The responsibility system is, in any case, expected to cost to car producers and, in 1998, Volvo allocated 40 million SEK to meet the costs involved. The possibility of a direct management of the scrapping fund by car industry, not accepted in the ordinance, is currently under re-examination in the light of producer responsibility’s implications (personal communications).

Various implementation and effectiveness problems are envisaged by car producers. Dismantlers premium is too low to provide incentives for appropriate dismantling and contractual proposal on average price are on going. The ordinance is considered to be lacking on the dismantling phase and the authorisation procedure is loose. The dismantling certificate system is subject to administrative problems and only 121,830 certificates of dismantling were issued in 1996. Car dismantler can continue to operate outside any network with car producers, and the latter requested a more stringent regulation on these activities in order to reach the targets (see BIL 1997). A limitation to the development of a dismantling network is the too low density of cars in Sweden combined with the low technical capabilities level of most dismantlers. Over 700 dismantling companies are registered and only 400 actually operate. Among the latter around 70 have the adequate capabilities for comply with stringent regulation. During the last few years some car dismantlers have started to adapt to ISO 14000 standards. The possibility is that, by gaining appropriate experience, the number can increase up to 150 in the future. One additional limitation is the small domestic market for recycling. There is not enough scale to support substantial national markets for recycled materials. Although it is possible to put incentives in the system, the infrastructure is very small and then the costs too high. Finally, the
consideration of alternative incentive instruments, e.g. increasing landfill taxes, was lacking in regulation making (personal communications).

Since the early 1990s, the Swedish car industry is developing cooperative efforts at the technical level. The initiatives are coordinated by BIL and are also in connection with the international actions in the EuCar-ACEA framework and in cooperation with VDA (Germany) and RAI (the Netherlands). The two main producers, Volvo Car Corporation and Saab, are involved in the above initiatives and are pursuing initiatives at the company level as well.

II.5.2. Volvo Car Corporation

Volvo started to address the management of ELV in early 1990s under the expectation of the introduction of producer responsibility in Sweden. The main direction of activity has been the development of DFD and DFR and the exploration of the most appropriate balance between different forms of recycling and ASR recovery.

The reference activity has been the ECRIS project (Environmental Car Recycling in Scandinavia). The project started in 1994 and was concluded in 1998 but a continuation is currently envisaged. It was carried out in cooperation with one big dismantler (Jonkopings Bildemontering AB) and two shredders (Stena Bilfrafgementering AB and AB Gotthard Nilsson) forming a reference group to which other partners cooperated (SBR, the Swedish Association of Motor-Car Scrappers; BIL, the Swedish Association of Automobile Manufactures and Wholesalers, and research institutions). The project was tailored to the Swedish conditions but it was also connected to European level efforts, in particular to the activities in the EuCar framework (see ECRIS 1998). ECRIS was structured in sub-projects: (a) LCA; (b) methods and tools (dismantling); (c) material recycling; (d) energy recovery; (e) hazardous waste; (f) economic aspects.

The main conclusions of the LCA sub-project are about the environmental implications of different options for ELV recycling and recovery. The sub-project is based on a methodology which includes the use of the Environmental Product Strategy (EPS) system developed by ten Swedish companies including Volvo, and the calculation of Environmental Load Units (ELUs), a composite index that puts in one figure the inventory and classification of environmental effects. The methodology obviously suffers from the problem of weighting of different effects and it is open to progressive refinements. The system is very flexible by allowing to take into account the change in the parameters also due to technological innovation (personal communications).

One major result of the LCA sub-project is that recovery actually creates a positive environmental loading that compensates for the negative ones occurring during car production and service life. However, there are minor differences and no substantial gains between recovering at 75% or 85% rate, given that the latter increases the positive environmental effect by 2% only. The recovery rates analysed include 3% additional recycling (plastics) and 7% additional energy recovery. LCA applied to end-of-life products from the dealers service points network suggest substantial environmental gains. The recycling of PP/EPDM, PP, ABS, PE, other plastics, aluminium, sheet steel can supply a positive environmental impact of 350,000
Regulation and Innovation in the area of End-of-Life Vehicles: ELV policies and initiatives

ELU/year. The economic cost, however, is unfavourable given that the cost of environmental processing of materials is greater than the return at current prices (Table II.5.2).

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity (ton/year)</th>
<th>Financial cost/benefit SEK/year</th>
<th>Environmental impact ELU/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP/EPDM</td>
<td>460</td>
<td>-</td>
<td>-214,000</td>
</tr>
<tr>
<td>PP</td>
<td>25</td>
<td>-</td>
<td>-12,000</td>
</tr>
<tr>
<td>ABS</td>
<td>2</td>
<td>-</td>
<td>-1,600</td>
</tr>
<tr>
<td>PE</td>
<td>10</td>
<td>-</td>
<td>-4,600</td>
</tr>
<tr>
<td>Other plastics</td>
<td>175</td>
<td>-</td>
<td>-117,000</td>
</tr>
<tr>
<td>Aluminium</td>
<td>88</td>
<td>-</td>
<td>-117,000</td>
</tr>
<tr>
<td>Sheet steel</td>
<td>22</td>
<td>-1,660,000</td>
<td>-4,400</td>
</tr>
<tr>
<td>Transport</td>
<td>300,000</td>
<td>-310,000</td>
<td>+5,000</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>-1,970,000</td>
<td>-350,000</td>
</tr>
</tbody>
</table>

ELU = Environmental Load Units

On the practical side, LCA is currently used in components choice for any new model. Economic evaluation enters in the final stage of the procedure.

The sub-project on methods and tools primarily addressed the dismantling operations and their extension to currently non-dismantled non-metallic materials, in particular plastics, rubber and glass. The current content of plastics in Volvo S40 is shown in Table II.5.3.

<table>
<thead>
<tr>
<th>Material</th>
<th>Percent by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP/EPDM</td>
<td>34%</td>
</tr>
<tr>
<td>PP</td>
<td>32%</td>
</tr>
<tr>
<td>PE</td>
<td>15%</td>
</tr>
<tr>
<td>PUR</td>
<td>9.5%</td>
</tr>
<tr>
<td>PMMA and ABS</td>
<td>4%</td>
</tr>
<tr>
<td>ABS</td>
<td>2.5%</td>
</tr>
<tr>
<td>PET</td>
<td>1.5%</td>
</tr>
<tr>
<td>EPP</td>
<td>1.5%</td>
</tr>
<tr>
<td>Memo: plastic share in car weight</td>
<td>6%</td>
</tr>
</tbody>
</table>

The experiences of dismantling efficiency were made on different Volvo models. The weight dismantled, the number of parts and dismantling efficiency (kg per minute) were measured in the
different hypothesis of dismantling equivalent to 3% or 6% of car weight. The results differ for the different models but, in general, the complexity of dismantling increases with the number of plastic parts and the dismantling efficiency decreases correspondingly (Table II.5.4).

Table II.5.4. Dismantling performance for different Volvo models
(for dismantling corresponding to 6% of total weight)

<table>
<thead>
<tr>
<th>Model</th>
<th>Number of parts dismantled</th>
<th>Total weight dismantled (kg)</th>
<th>Dismantling efficiency (kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volvo 200*</td>
<td>99</td>
<td>63.49</td>
<td>0.66</td>
</tr>
<tr>
<td>Volvo 300</td>
<td>88</td>
<td>73.02</td>
<td>0.46</td>
</tr>
<tr>
<td>Volvo 400</td>
<td>145</td>
<td>57.99</td>
<td>0.39</td>
</tr>
<tr>
<td>Volvo 700</td>
<td>138</td>
<td>84.21</td>
<td>0.45</td>
</tr>
<tr>
<td>Volvo 900</td>
<td>140</td>
<td>84.44</td>
<td>0.36</td>
</tr>
<tr>
<td>Volvo 850</td>
<td>130</td>
<td>84.66</td>
<td>0.38</td>
</tr>
<tr>
<td>Volvo S40</td>
<td>130</td>
<td>70.78</td>
<td>0.52</td>
</tr>
<tr>
<td>Volvo V40</td>
<td>135</td>
<td>72.22</td>
<td>0.52</td>
</tr>
</tbody>
</table>

* Dismantling for 5% of total weight

Source: adapted from ECRIS (1998).

Higher efficiency in dismantling is in general associated to the older models (Volvo 200 and 300), which were simple in design and had less plastics, and the most recent models (Volvo S40 and V40), which include new concepts in design and take into account dismantability and recyclability to some extent.

Another area of ECRIS was the recycling of materials (plastic, wiring, tyres, catalytic converters, glass, aluminium). Various initiatives to create marketing opportunities for recyclable materials were activated in Sweden and other countries. A mixed picture of opportunities and constraints emerged. In general, the creation of additional economic outlets is constrained by the small domestic market, the low quality of material, the remaining problems in material identification. This notwithstanding, some plastics have been successfully tested for the inclusion in new cars. Recycled materials are already used in all new Volvo car models. The Volvo S80, for example, contains 20 kg of recycled plastics.

Pilot projects on energy recovery of ASR in the framework of ECRIS (20% ASR with municipal solid waste), gave rise to good technical results. Drawbacks emerged, however, for the excess costs incurred, given that in Sweden it is cheaper to landfill. Nonetheless, ASR can increase the heat value of refuse-derived fuel and have no practical oppositions (personal communication).

On hazardous waste, the different experiences of ECRIS highlighted that it is possible to have a process of energy recovery of the shredder light fraction with low level of hazardous substances. More in general, Volvo has a specific policy for technical specification to suppliers regarding hazardous substances.
The analysis of economic aspects of ELV recovery was carried out by a specific subproject that simulated the costs of 80% and 85% rates of recovery with different combinations of additional mechanical recycling (from 1.5% to 6%) and energy recovery (from 3% to 7%). In general, an increase of recovery rates gives rise, in the present market situation, to an increase of costs and the two variables are exponentially related. The most important variables are the costs of extra dismantling, the price for recycled plastics and glass, the price for energy recovery for SR and tyres, the level of landfill taxes (Table II.5.5). The value of spare parts that can be sold has a great significance for the profitability of operations (personal communications).

Starting from ECRIS results and the ongoing developments of EuCar common DFD/DFR guidelines, the Volvo strategy on DFD/DFR is based on a set of guidelines to be applied to all the parts and components of each new model. The guidelines can be intended as an instrument for reaching a good compromise between the different needs and to facilitate the evaluations of the different alternatives (personal communications).

The general priorities are: (a) to avoid hazardous material and substances; (b) to facilitate drainage and removal of hazardous materials; (c) to make a resource efficient production; (d) to design component in a way that facilitates recycling (Volvo Car Corporation 1997).

**Table II.5.5. Economic implications of increasing recovery rates**

<table>
<thead>
<tr>
<th>Recovery rates</th>
<th>Average profitability and decreases (per car, 1996, SEK)</th>
<th>Uncertainty range</th>
</tr>
</thead>
<tbody>
<tr>
<td>75% recovery</td>
<td>4,800</td>
<td>2,000-5,000</td>
</tr>
<tr>
<td>80% recovery (+1.5% recycling, +3.5% energy)</td>
<td>- 130</td>
<td>- 100-150</td>
</tr>
<tr>
<td>80% recovery (+2% recycling, +3% energy)</td>
<td>- 335</td>
<td>- 300-400</td>
</tr>
<tr>
<td>85% recovery (+3% recycling, +7% energy)</td>
<td>- 340</td>
<td>- 300-400</td>
</tr>
<tr>
<td>85% recovery (+6% recycling, +4% energy)</td>
<td>- 720</td>
<td>- 600-800</td>
</tr>
</tbody>
</table>

Source: ECRIS (1998) and personal communications.

The priority of avoiding hazardous materials is pursued primarily by the “Volvo Black & Grey List” for suppliers that indicates the materials to be avoided. The second priority is based on the requirement that all parts containing hazardous substances (all fluids, batteries, wheel balancing weights, airbag systems) must be designed in a specific way, easily accessible and removable. The third priority is addressed by specific guidelines on production-waste avoidance and recovery during the production process. The fourth priority of designing components for recycling is based on specific suggestions summarised in Table II.5.6. Dismantling manuals are available for most of Volvo’s trucks, buses and construction equipment. Since 1997, Volvo has published dismantling manuals for its car models from 1982 on.

According to Volvo the actual possibility to calculate “recyclability coefficients” in the framework of DFR for cars remains a moot point. The coefficients largely depend on the whole way the car is designed and on what infrastructure is available for dismantling and recycling not
only at present but also into the future. It is, therefore, extremely difficult and potentially misleading to include recyclability coefficients in type approval, also because the latter is given 10 years or more before the car become ELV and what matters is the most likely degree of ex post recyclability. Figures can be only rough indicators rather than precise measures (personal communications).

During the last few years, a trend towards fewer polymers in Volvo cars is emerging but it is not primarily caused by recycling concerns, although it has effects on recycling. It is in fact caused also by cost considerations: a reduced number of plastics is easier to manage in assembling - and then also in dismantling. The trend can affect the fibre-based new advanced materials thus creating some concerns, although Volvo is currently not using extensively advanced fibre-reinforced plastics. There is the technical possibility to make these materials more recyclable (personal communications).

DFD and DFR is partly shifting the responsibility on recyclability to component producers and material suppliers. Further to guidelines for suppliers, Volvo check the compatibility between prescription and the features of components.

Table II.5.6. Guidelines on components for facilitating recycling

<table>
<thead>
<tr>
<th>Areas</th>
<th>Aims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material choice</td>
<td>Avoidance of materials not suitable for recycling</td>
</tr>
<tr>
<td></td>
<td>Minimising different materials</td>
</tr>
<tr>
<td></td>
<td>Sortability</td>
</tr>
<tr>
<td></td>
<td>Compatibility</td>
</tr>
<tr>
<td>Marking</td>
<td>Easy to read size</td>
</tr>
<tr>
<td></td>
<td>Location easy to find</td>
</tr>
<tr>
<td>Attachment elements</td>
<td>Integrated snap-in elements</td>
</tr>
<tr>
<td></td>
<td>Easy to remove</td>
</tr>
<tr>
<td></td>
<td>Small quantities and uniform</td>
</tr>
<tr>
<td>Surface treatment</td>
<td>Avoidance of surface treatment</td>
</tr>
<tr>
<td></td>
<td>Surface material compatible with bearer material</td>
</tr>
<tr>
<td>Glue/tape/labels</td>
<td>Compatible with bearer material or easy to remove</td>
</tr>
<tr>
<td>Use of recycled materials</td>
<td>Primarily in covered applications with low stress levels</td>
</tr>
<tr>
<td>Metals</td>
<td>High value metals -Cu, Al, Mg-possible to remove before fragmentation</td>
</tr>
<tr>
<td></td>
<td>When different metals together, suitable for recycling as a high value alloy</td>
</tr>
<tr>
<td>Glass</td>
<td>Keep free of contaminating printing or attached materials</td>
</tr>
<tr>
<td></td>
<td>Attachment adapted to facilitate removal</td>
</tr>
</tbody>
</table>

Source: adapted from Volvo Car Corporation (1997).
The possible environmental trade-offs created by recyclability on energy-emission requirements are considered not so significant for the moment, but some problems can arise with thermosets. The possible trade-off is solvable only by innovating in recycling of light materials and by finding balances at the policy-making level. If the latter are not possible, the priority is for saving energy and greenhouse gas emissions (personal communications).

According to Volvo, there is the possibility to reach the 2002 targets of 85% recovery with a combination of +3% recycling and +7% energy recovery (total +10%). However, if recycling should have to be more than +3% and energy recovery less than +7%, there will be a strong costs increase. Swedish carmakers are responsible for the last 5 tyres in the car and therefore, if they are taken away before shredding, their weight might be included in the recovery rate (personal communications).

In 1998, Volvo developed a network of associated dismantlers serving also other carmakers. They are 70 out of a total number of a total 300-400 in Sweden and they work under bilateral contracts. They have been selected as those able to fulfill the requirements of Swedish legislation on depollution. The objective is to push the 70 dismantlers to extract more recyclable materials. Volvo is currently involved in negotiations with potential working partners for introducing a similar system in Japan.

Both Volvo cars and trucks operate factory-reconditioned parts exchange systems. Reconditioned parts to a value of almost SEK 2,500 million were sold during the year. Since 1998, cars, trucks and buses have operated a joint system of collecting and recycling used oil filters from service workshops in Sweden. An estimated 750,000 filters will be collected annually under the scheme. In 1999, it is intended to sign an agreement under which other waste products will be collected from service workshops in similar manner.
II.6. The United Kingdom

New car registrations in the United Kingdom in 1998 were 2,247,403 (16.1% of total EU15). The number of ELV was estimated at 1.4 million units in 1994 and the amount of ASR at 300,000 tons in the same year (IPEE 1996). More recent estimates suggest a number of 1.9 million ELVs in 1997 and an amount of ASR around 500,000 tons (ACORD 1998).

II.6.1. The ACORD agreement

The ELV policy developments in the United Kingdom started from the involvement of industry and government in the activities of the CEST Group and resulted in the ACORD initiative (Automotive Consortium on Recycling and Disposal). The ACORD agreement came at the end of six years of research, discussion, and negotiations. After a preliminary plan in 1992, ACORD launched the implementation plan in 1995. The agreement was signed in July 1997 and it involves the car manufacturers and importers, material and component suppliers, shredders, dismantlers, recycling industry and the Departments of Industry and of Environment. The main objectives of ACORD are to reduce ASR landfilling, to organise an ELV treatment system, to develop appropriate recycling and disposal options, and, on policy-making grounds, to avoid a European directive.

The principles of ACORD are those of shared responsibility and coordinated actions by the various industries. ASR energy recovery was included among the possible solutions. ACORD can be defined as a “unilateral” private contract, insofar the role of the public regulator is one of formal support and participation to policy discussion (personal communications). No direct involvement by the government occurred so far, leaving achievements to rely completely on market forces and private enterprises (see ACORD 1998, Hulse 1999).

ACORD is supported by an industry consortium, CARE (Consortium for Automotive Recycling), representing 75% of carmakers operating in the United Kingdom. CARE is a self-funded consortium and it overlaps ACORD as far as policy objectives are concerned, but with the specific task of discovering and improving disposal technologies. (see CARE 1998). CARE worked since 1996 on a number of pilot projects concerning both mechanical recycling and

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52 The analysis is also based on the interview with David Hulse (ACORD). Derek Wilkins (Rover Group Ltd) supplied the documents on the CARE project.

53 The signatories of ACORD agreement 1997 are: Society of Motor Manufactures and Traders (SMMT); British Metals Federation (BMF); Motor Vehicle Dismantlers Association (MVDA); British Plastics Federation (BPF); British Rubber Manufacturers Association (BRMA). The discussion leading to ACORD involved the Department of the Environment, Transport and Regions and the Department of Trade and Industry. Since 1997, the involvement in ACORD extended to representatives for the glass industry, the Retail Motor Industry Federation, the Surface Engineering Association, and the leading vehicle and component manufacturers (see ACORD 1998).
energy recovery. CARE acts as a research parallel (but autonomous) consortium, providing results for technological feasibility and economically viability of disposal options.

The commitment set up by the ACORD agreement is to achieve a recovery rate of 85% by 2002 and 95% by 2015.\textsuperscript{54} Recovery is to be meant as a joint use of recycling and energy recovery. The ACORD approach seems to be oriented toward energy recovery as a priority option. ACORD and CARE representatives seem to argue that recycling opportunities (markets, technologies/capabilities) will not sufficiently develop and expand to make targets achievable (personal communications). Strong research and investment effort is then needed on energy recovery options and, in this regard, shredders industry plays a major role. ACORD lists energy-recovery priorities as fuel electricity generation, blast furnaces and cement kilns.

Responsibilities along the ELV chain are distributed in the following way (see SMMT et al. 1997):

- vehicle manufacturers will work on making their cars more suitable for recycling, by selection of materials, acceptance and discovery of uses for downstream recycled materials, and (in some instances) by enhancing the energy value contained;
- dismantlers will have to remove more non-metallic materials, to reduce as far as possible the delivery of mixed materials both to shredders and to collectors for recycled materials; they must provide quality feed for recycling purposes and incineration purposes so that both innovation paths are exploited;
- shredders will have to co-operate with and incentive upstream agents to minimise the amount of non-ferrous material; their role is fundamental in finding new feasible ways of energy recovery;
- plastics and rubber industries will have a central role in developing further applications and create markets for recycled components and materials;
- last owners will have to be encouraged to deliver scrapping cars to approved and certified dismantler sites;
- the government will have to support and monitor the agreement; bodies such as the Environment Agency should ensure that all disposal agents are meeting the same standards of environmental protection.

Public intervention will be in the form of external support, mainly aimed at regulating the dismantling sector. The European directive is considered to be over-regulating ELV waste management by introducing financial instruments (FTB) which will bring about market distortion (personal communications).

ACORD is supporting the idea that the choice between recycling and incineration should be freely left to market force decisions. At current stage, ACORD argues that the achievement of ELV targets would need more effort in developing energy recovery alternatives, as recycling oriented markets are not reliable and still not well developed.

\textsuperscript{54} ACORD explicitly stated that 2002 is set to allow time for completion of the legislative process.
II.6.2. Achievements

At present, most of the results achieved by the agreement correspond to the activities of the participating industries in their respective fields. The 1997 ACORD monitored share of recovered material is 75% of total weight of material for disposal. The remaining 25% is landfilled. Only 500 dismantler out of 2,000 are currently licensed in the United Kingdom. The availability of dismantling manuals and the marking of plastic parts is going on but it is still far from completion.

The recovery rates of plastics and rubber are still low. The most of recycling occurs with respect to ferrous metals (61% of total car weight recycled); other recovery streams occurs with re-used parts (9%), tyres re-used (1%) and recycled (0,4%), batteries recycling (0,5%), fluids recovered (2%), non ferrous materials (2%), while the shares of recovered plastics and glass are negligible or nil. The 25 % of ASR landfilled waste is composed of glass (11% of ASR), tyres (11%), seatfoam (7%), battery (4%), fluids (4%), thermoplastics I (19%)55, thermoplastics II (10%), thermosets (6%), rubber (15%), other (13%) (see ACORD 1998). Some key indicators on ELV recovery in the UK in 1997 and the actions by industry are summarised in Table II.6.1.

The performance in 1998 is summarised in Table II.6.2. The deterioration in performance between 1997 and 1998 is considered to be disappointing and is due, almost entirely, to adverse conditions in the markets for parts and materials. Progresses have been made, however, in the area of dismantling manuals and parts marking systems. At the end of 1998, dismantling manuals was reported to be 69% complete. For most of the high volume models dismantling manuals cover 95% of the market. Major manufacturers committed to use IDIS (International Dismantling Information System). Car manufacturers are committed to mark with a common coding all plastic parts over 100 grams in order to ease identification for recycling. By the end of 1998, completion of this task had improved from 73% to 95%, with the high volume models treated as a priority.

In the field of parts re-manufacturing, at the end of 1998, vehicle manufacturers service exchange schemes covered a range of around 150 parts and were believed to be responsible for approximately 4,000 tonnes of material being recovered.

55 Polypropylene (PP), Polyethylene (PE), Acrylonitrile Butadiene Styrene (ABS).
### Table II.6.1. Key indicators of ELV recovery in the UK in 1997 and the actions by industries

<table>
<thead>
<tr>
<th>Industry</th>
<th>Key data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle manufacturers</strong></td>
<td></td>
</tr>
<tr>
<td>Dismantling instructions available</td>
<td>46% completed (mainly high volume car that represent 90% of the domestic market)</td>
</tr>
<tr>
<td>Plastic parts marking completion</td>
<td>73%</td>
</tr>
<tr>
<td>Recyclability measurement criteria</td>
<td>To be established</td>
</tr>
<tr>
<td><strong>Motor vehicle dismantlers</strong></td>
<td></td>
</tr>
<tr>
<td>Number of licensed dismantlers</td>
<td>2,000</td>
</tr>
<tr>
<td>Estimated number of unlicensed dismantlers</td>
<td>1,500</td>
</tr>
<tr>
<td>Parts removed for re-use</td>
<td>207,000 tonnes (around 10% of total weight for disposal)</td>
</tr>
<tr>
<td>Parts removed for recycling</td>
<td>141,000 tonnes</td>
</tr>
<tr>
<td>Fluids drained for recycling</td>
<td>45,000 tonnes</td>
</tr>
<tr>
<td>Recovery percentage by weight</td>
<td>19.2% (out of 2,007,500 tonnes)</td>
</tr>
<tr>
<td><strong>Shredders</strong></td>
<td></td>
</tr>
<tr>
<td>Number of shredding sites</td>
<td>47</td>
</tr>
<tr>
<td>Ferrous metal recovered</td>
<td>1,224,000 tonnes</td>
</tr>
<tr>
<td>Non-ferrous metal recovered</td>
<td>34,000 tonnes</td>
</tr>
<tr>
<td>SR energy recovery</td>
<td>Negligible</td>
</tr>
<tr>
<td>SR to landfill</td>
<td>502,000 tonnes</td>
</tr>
<tr>
<td>Recovery percentage by weight</td>
<td>71.5% (out of 1,760,000 tonnes)</td>
</tr>
<tr>
<td><strong>Plastics industry</strong></td>
<td></td>
</tr>
<tr>
<td>Plastics available from ELVs</td>
<td>142,000 tonnes</td>
</tr>
<tr>
<td>Plastic recycled from ELVs</td>
<td>5,000 tonnes</td>
</tr>
<tr>
<td>Recycled plastics used in automotive applications</td>
<td>To be established</td>
</tr>
<tr>
<td><strong>Rubber industry</strong></td>
<td></td>
</tr>
<tr>
<td>Rubber available from ELVs</td>
<td>136,000 tonnes</td>
</tr>
<tr>
<td>Rubber recovered (tyres)</td>
<td>25,000 tonnes</td>
</tr>
<tr>
<td>Recovery rate</td>
<td>18.3%</td>
</tr>
<tr>
<td><strong>Glass industry</strong></td>
<td></td>
</tr>
<tr>
<td>ELV glass sold for re-use via dismantlers</td>
<td>8,000 tonnes</td>
</tr>
<tr>
<td>ELV glass recycled</td>
<td>500 tonnes</td>
</tr>
</tbody>
</table>

Source: adapted from ACORD (1998).
Table II.6.2.
1998 material recovery performance (tons)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>1997 (amended)</th>
<th>1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of End of Life Vehicles (units)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars</td>
<td>1,700,000</td>
<td>1,600,000</td>
</tr>
<tr>
<td>Vans</td>
<td>200,000</td>
<td>200,000</td>
</tr>
<tr>
<td>Total</td>
<td>1,900,000</td>
<td>1,800,000</td>
</tr>
<tr>
<td>Average Weight of Vehicle (Kgs)</td>
<td>1025</td>
<td>1030</td>
</tr>
<tr>
<td>Weight of Vehicles for Disposal</td>
<td>1,947,500</td>
<td>1,854,000</td>
</tr>
<tr>
<td>Weight of Part Exchanged Core Units (Engines/Gearboxes etc.)</td>
<td>60,000</td>
<td>30,000</td>
</tr>
<tr>
<td>Total Weight of Material for Disposal</td>
<td>2,007,500</td>
<td>1,884,000</td>
</tr>
<tr>
<td>Weight of Parts Re-Used</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Types</td>
<td>207,000</td>
<td>193,000</td>
</tr>
<tr>
<td>Weight of Material Recycled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferrous Metal</td>
<td>1,200,000</td>
<td>1,094,000</td>
</tr>
<tr>
<td>Non Ferrous (Shredders)</td>
<td>34,000</td>
<td>33,000</td>
</tr>
<tr>
<td>Non Ferrous (Dismantlers)</td>
<td>22,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Plastics</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Tyres</td>
<td>8,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Fluids (including fuel)</td>
<td>45,000</td>
<td>43,000</td>
</tr>
<tr>
<td>Batteries</td>
<td>10,000</td>
<td>9,000</td>
</tr>
<tr>
<td>Glass</td>
<td>500</td>
<td>2,500</td>
</tr>
<tr>
<td>Sub-total Material Recycling</td>
<td>1,320,500</td>
<td>1,205,500</td>
</tr>
<tr>
<td>Total Material Recovery</td>
<td>1,527,500</td>
<td>1,398,500</td>
</tr>
<tr>
<td>Landfill of Residue</td>
<td>480,000</td>
<td>485,500</td>
</tr>
<tr>
<td>Recovery Percentage</td>
<td>76%</td>
<td>74%</td>
</tr>
</tbody>
</table>


The key facts about dismantling industry in the United Kingdom are summarised in Table II.6.3. The 334 members of Motor Vehicle Dismantlers Association of Great Britain (MVDA) handle nearly 50% of the UK market for ELVs. The remainder is made up of a small number of large salvage specialists dealing in damaged cars and a large number of smaller dismantlers and car breakers who deal with approximately 20% of ELVs.

In 1998, the majority of vehicles handled by dismantlers were those manufactured between 1984 and 1986. Vehicles from this period demonstrated an increased use of plastics compared to earlier models, particularly for bumpers. The markets for glass for recycling and tyres for remoulding have virtually disappeared. In particular, the remould tyre industry continues to suffer badly due to competitive pressure from cheap imports. There has been no significant change in the amount of fluids removed for re-use and recycling.

High costs for dismantling and low returns for materials, including a fall in the value of the metal content of ELVs, has meant that dismantlers have had to concentrate their efforts on increasing parts sales. As a result, more dismantlers are turning to accident damaged late vehicles (post 1990) in order to generate revenue. During 1998, dismantlers started to become reluctant to collect or accept older ELVs, even if they were offered free of charge.
Table II.6.3
The dismantling industry in the United Kingdom

<table>
<thead>
<tr>
<th></th>
<th>1997</th>
<th>1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Licensed or Licence-Exempt Dismantlers</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Estimated Number of Unlicensed Dismantlers</td>
<td>1,500</td>
<td>1,500</td>
</tr>
<tr>
<td>Weight of Vehicles for Dismantling</td>
<td>1,947,500 Tonnes</td>
<td>1,854,000 Tonnes</td>
</tr>
<tr>
<td>Weight of Part Exchanged Core Units</td>
<td>60,000 Tonnes</td>
<td>30,000 Tonnes</td>
</tr>
<tr>
<td>Total Weight of Material for Disposal</td>
<td>2,007,500 Tonnes</td>
<td>1,884,000 Tonnes</td>
</tr>
<tr>
<td>Weight of Parts Removed for Re-Use</td>
<td>207,000 Tonnes</td>
<td>193,000 Tonnes</td>
</tr>
<tr>
<td>Weight of Parts Removed for Recycling *</td>
<td>141,000 Tonnes</td>
<td>114,000 Tonnes</td>
</tr>
<tr>
<td>Weight of Fluids Drained for Recycling</td>
<td>45,000 Tonnes</td>
<td>43,000 Tonnes</td>
</tr>
<tr>
<td>Recovery Percentage by Weight</td>
<td>19.2 %</td>
<td>18.6 %</td>
</tr>
</tbody>
</table>

* Including ferrous and non-ferrous metals
Source: ACORD (1999)

II.6.3. The CARE consortium

The CARE consortium started activities in 1995 and carried out pilot projects to assess the technical and economical feasibility of recycling and incinerating operations aimed at recovering glasses, tyres, seatfoam, thermoplastics, battery, fluids. These categories of residues represent 55% of total ASR waste going to landfill (see CARE 1998).

The CARE study investigates disposal possibilities on the basis of the following common actions as agreed with ACORD:

- to increase plastic recovery by better separation processes;
- to develop applications and markets for recycled plastics;
- to increase recovery of fluid by de-pollution;
- to reduce metallic content of shredder residue;
- to improve tyre recovery;
- to initiate rubber and glass recovery processes;
- to develop ASR recovery processes.

CARE is organised by projects which responsibility is assigned to a car manufacturer. The distribution of projects is illustrated in Table II.6.4.
The CARE Project Teams

<table>
<thead>
<tr>
<th>Project</th>
<th>Leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dismantler Standards</td>
<td>Vauxhall</td>
</tr>
<tr>
<td>Tyres and Elastomers</td>
<td>Ford / Jaguar</td>
</tr>
<tr>
<td>Fluids and Depollution</td>
<td>Toyota</td>
</tr>
<tr>
<td>Hulk Standards</td>
<td>Volvo</td>
</tr>
<tr>
<td>Glass Recovery</td>
<td>Mercedes</td>
</tr>
<tr>
<td>Energy Recovery</td>
<td>Peugeot/Citroen</td>
</tr>
<tr>
<td>Plastics Recovery</td>
<td>Rover</td>
</tr>
<tr>
<td>Future Materials</td>
<td>Ford/Jaguar</td>
</tr>
<tr>
<td>Communications</td>
<td>Volkswagen</td>
</tr>
<tr>
<td>Safety Restraint Systems</td>
<td>Nissan</td>
</tr>
<tr>
<td>Re-Use and Re-Manufacturing</td>
<td>Honda</td>
</tr>
<tr>
<td>Tooling Development</td>
<td>Colt Cars (representing Mitsubishi)</td>
</tr>
</tbody>
</table>

Note: BMW, Fiat and Renault recycling activities are represented in UK by Rover.

The CARE results show that a consistent amount of plastics (PP, ABS\(^56\)) can be cleaned and segregated quite easily before crushing, but further marginal efforts would require substantial increase in labour time, possibly making the process uneconomic. The recovery of materials has shown to be viable, as after granulation plastics show to have properties not different from the virgin material. ABS is removed before crushing in reasonable time. All plastics should be free of metal contamination before granulation occurs. ABS is associated to returns which range between £800 to £500 per tonne, although sustainable markets still has to develop. The quality and cleanness of the stream is the major issue to be addressed. PP is the most common plastic in automotive construction. After segregation from other plastics and de-contamination from metals, oils, and labels, granulation is necessary to provide materials to both the automotive industry and other non automotive sectors (i.e. shoes production). Provided that the virgin material price is not abnormally low, profits per tonne are about the amount estimated for ABS. Finally, PE recovery (seatfoam) has shown to be viable for conversion into chipfoam; being a thermoset material, it cannot be remelted to form another product. Therefore recovery is different from that of other thermoplastics, because it has to be used in the form it is recovered. Recovery is quite costly as substantial de-contamination from disturbing elements is necessary, but some profits can accrue to dismantlers (about £12/hour).

As far as glass is concerned, the long recovery time associated to the depressed market for recovered glass currently makes the process unprofitable. Although the recycling of glass is a very well understood process, only part of car glass is easily economically removed at dismantling sites, and then the supply to secondary markets is highly depends on external forces.

The scheme for tyres has demonstrated that barely half of tyres can be recovered with positive value, the remainder — having negative value — being sent to energy recovery sites or to landfilling. Tyres represent the most difficult component (together with glass) as far as disposal is concerned, being recycling constrained and energy recovery not always feasible\(^57\). A strong

\(^{56}\) Interior trims.

\(^{57}\) Cement kilns appear as the only feasible, but not well-developed, process to use tyres as fuel.
influence in the short term has been exercised by adverse exchange rate conditions, so that the recycling process could end up with being cheaper in the long run under average conditions.

Seat belts dismantling process has shown not to be profitable (£/hour) mostly due to depressed secondary markets.

The shredder residue underwent many pilot studies in order to test what the calorific value is and what it depends on. The objective is to determine the composition and variability that may be expected, so its suitability as a energy feed. Results have indicated that the residue has a calorific value half of that of coal. Strong marginal improvements are possible if better pre-treatment (i.e. de-polluting operations) are carried out at dismantlers and better design is introduced in car making. Cement kilns, blast furnaces and municipal waste has been under investigation for future potential opportunities. The scenario for using shredder residue in energy recovery processes within the UK does not look very encouraging in the short and medium term, so that current expectations are biased toward long run achievements.

The first CARE study has demonstrated the technical feasibility of recovering and recycling half of the flow of non-metallic materials from ELV. This represents 15% of total car weight, so that together with the metallic content gives a total 88% technically feasible ELV recovery rate. The achievement of such short-term target depends on the feasibility of energy recovery as a disposal option (i.e. for tyres). The set of innovations which exert a central influence on the waste management processes are the following: (a) marginal increasing plastic recycling (existing and new uses/applications); (b) marginal effort in de-polluting and de-contaminating; (c) effort in pre-treatment of materials; (d) making glass and rubber more recyclable; (e) investments in ASR energy recovery.

The next phase of CARE project will be focusing on the remaining 45% of ASR, that is thermoplastics, thermoset, rubber-seals, and others (e.g. wood, bitumen) (see CARE 1998).
II.7. Other European countries

II.7.1. Austria

The estimated number of ELVs in Austria was 90,000 units in 1997. The average age of ELVs was about 10-12 years and their market value was, on average, negative (up to 100 EUROs). Cars are normally drained by the dismantlers (200 companies and over 5,000 garages also perform dismantling activities) before shredding. Six shredder companies in Austria perform the operations leading to a recovery rate of 74% of total weight and 23% of ASR landfilling. The landfill of shredder residues is likely to be influenced by the new legislation, which came into force in 1997.

The legislation framework for ELV is based on the General waste management Act (Abfallwirtschaftsgesetz - AWG), the Decree by the Ministry of Environment (August 16th, 1995) defining the minimum standards for the treatment of ELVs (collection, draining, dismantling, shredding), the Festsetzungsverordnung 1997 defining hazardous materials, and the Landfill decree of 1996 establishing regulations for the treatment of shredder residue before landfill. The Festsetzungsverordnung 1997 also defines the list of hazardous and non-hazardous wastes from ELVs. A decree, which is expected to regulate the collection and treatment of ELVs is discussed since some years and it is postponed until the EU Directive on ELVs will be adopted.

A non-legally binding voluntary agreement on ELV (Alt-Pkw-Recycling Vereinbarung) has been signed in 1992 between the Ministry of Environment, the Ministry of economic affairs and the Chamber of commerce (also representing the Austrian car-industry) to assure car-recycling at high environmental and technical standard. The non-statutory targets are: 80% "recycling" and 95 "recycling" in the long term. Specific deadlines are not indicated. The agreement has been renewed in 1996. The agreement includes the obligation by car-dealers to take-back ELVs free of charge (FTB) when a new car is bought or at market conditions when a new car is not bought. The other main aspects of the agreement are:

- the introduction of certification for dismantlers and shredders;
- the introduction of a certificate of destruction for last owner;
- information to the last owner about the disposal of ELVs (list of taking back and dismantling companies);

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58 The analysis is based on Bundesministerium fur Umwelt et al. (1996) and personal communications from Org-Consult and Bernhard Boehm, Technical University of Wien.
the improvement of ELV treatment by compliance with the minimum standards of collection, dismantling and shredding.

The agreement includes the obligation for car manufacturers and importers to increase recyclable materials in car production, to reduce the number of different types of materials, to develop recycling-friendly design of new vehicles, and the increase of recycled materials in the production of new vehicles. Car dealers have the obligations to free take-back in the form described above, to issue a certificate of destruction (not necessary for de-registration), to deliver ELVs to authorised dismantler, and to supply annually the documentation of their activities and results. The dismantlers have the obligation to issue a certificate of destruction (not required for de-registration).

**II.7.2 Belgium**

The estimated number of ELVs in Belgium in 1997 was 300,000 units. Their average age was 13 years and their market value was positive on average.

The legislation framework on ELV reflects the Belgian administrative organisation in which the three regions Flanders, Wallonia and Brussels have each the competence to put into force environmental laws and decrees. The recent introduction of specific regulations on ELVs reflects the developments of the EU Directive proposal.

In Flanders, the legal framework on ELV is based on the legislation on waste management (the Decree of 2nd July 1981 on waste management, as amended by decree of 20th April 1994, and the decree of 2nd June 1994 on environmental agreements) and the specific legislation on the treatment of ELVs, approved 17th December 1997. The latter includes the following targets and obligations, closely reflecting the EU Directive proposal:

- no later than 1 January 2005, for all ELV, the re-use and recovery is increased to a minimum of 85% by weight; within the same time limit, the re-use and recycling is increased to a minimum of 80% by weight;
- no later than 1 January 2015, for all ELV, the re-use and recovery is increased to a minimum of 95% by weight; within the same time limit, the re-use and recycling is increased to a minimum of 85% by weight;
- from the 1st July 1999, every car dealer has to accept, without cost for the last owner, the old vehicle when he/she buys a vehicle of the same category (M1 or N1);
- from 1st July 2004, the official representative of the car manufacturer has to accept, without costs for the last owner, the old vehicle of his own brand, even when he/she does not buy

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59 The analysis is based on Peelman (1999) and personal communications from Org-Consult.
another vehicle, and provided that this vehicle was registered for the first time after 1st July 1999.

In Brussels, ELV regulation is included in the *Permis d'Environnement*. The stated targets and obligations are the same as in Flanders (see above). In Wallonia provisions on ELV are included in the Plan Horizon 2010 and additional legislation on ELV is planned.

In March 30th, 1999 a voluntary agreement was signed between the governments of Flanders, Wallonia and Brussels and the associations representing the industries of the ELV chain. The agreement is into force since 1st July 1999 and it is valid for 5 years. Therefore, only the targets and obligations for 2005 (as described above) are included in the agreement.

The industrial participants to the agreement are FEBIAC (Belgian Federation of Automotive and Cycle Industries); FEDERAUTO (Federation of Trade, Car Repair and related Sectors); GDA (Association of Distributors and Automobile Agents); the Traders in the Vehicles of Occasion; REPARAUTO (Association of the Companies of Automobile Repair); FEBELCAR (Royal Belgian Federation of the Body and the Related Trades); Federation of the Automobile Hardware; DETABEL (Association of Breakdown-service-Towing companies); FEGARBEL SERVICE; COBEREC (Belgian Confederation of Recovery); FEVAR (Federation of Car Recycling and Sale of Spare Parts Companies); FABRIMETAL; FECHIPLAST (Association of Plastic-Transformers); FEBELTEX (Belgian Federation of the Industry of the Textile). The three regional governments in the agreement are represented by their respective Ministries of the environment.

In the agreement, the main responsibilities of industrial actors are defined as follows:

- to increase R&D efforts by material suppliers to increase the amount of materials that can be recovered and recycled;
- to use of common components and material coding standards;
- to design cars and parts under consideration of material choice and recovery potential;
- car manufactures have to provide dismantling manuals for models registered after 1st July 1999; the dismantling manuals must include the location of dangerous materials, safety information and information about the dismantling of parts and materials;
- to establish a network of certified ELV treatment centres;
- the old vehicle shall be taken back without any costs to the last owner, if the vehicles is complete (no major parts missing) and it is registered in Belgium for at least 6 months, all legal documents can be provided and the vehicle is delivered to the place of acceptance by the car salesman.
- as from 1st July 2004, the official representative of the car manufacturer has to accept, without costs for the last owner, the old vehicle of his own brand, even when the latter does not buy another vehicle, and provided that this vehicle was newly registered after 1st July 1999;
- if any of these conditions are not fulfilled, the last owner could be requested to participate on
  the costs of recycling; to proof the acceptance to the last owner, it is necessary to mention
  the VIN number (identity number) of the old vehicle on the sales invoice of the “new” one;
- car dealers have the obligation to delivery ELVs only to authorised treatment centres.

Other specific rules have been established for deregistration, certificates of destruction, and
inspection on dismantlers/collectors. In particular, a vehicle for which the certificate of periodical
technical inspection has been expired for more than 12 months is considered to be an ELV. The
owner of such a vehicle can be fined, unless he has paid an ELV ownership tax. Last owner
delivering ELV to a certified treatment centre will receive a certificate of destruction, which is
the legal proof that the vehicle has been destroyed. Regional authorities will be responsible to
perform regular checks of car dumps and dismantlers to verify if the company manager can
provide, for all vehicles in the site, a certificate of technical inspection which has not expired for
more than 12 months.

II.7.3. Denmark

The estimated number of ELVs in Denmark in 1997 was 105,000 units. More recent data
indicate that 120,000 vehicles have been de-registered following a steadily increasing trend. The
average age of ELVs is 15 to 17, and the market value is negative (from –55 to -135 EUROs).
The dismantlers have to finance their business mainly by selling used spare-parts. The operating
dismantlers are 300-400, of which about 150 have a legal permission. The legal permission is
necessary if more than 5 ELVs are stored or more than 10 ELVs are treated in one year. There
are many small enterprises without a legal permission treating 20-30 ELVs per year. After the
new legislation will be into force (expected July.2000) the number of legally certified dismantlers
is expected to decrease down to around 150. Currently, dismantlers are organised in the Danish
Autorecyc ler’s Association (DAG) that has 90 members. DAG has introduced environmental
management standards since 1994. Over 30% of total ELVs are treated by dismantlers
organised in the DAG.

From January 1994 to June 1995 a car-scrapping scheme was implemented by the Danish
government.

The general legal framework of ELV is represented primarily by Environmental Protection Act
No. 698 of 22nd September 1998. According to the Environmental Protection Act, the
Government and local authorities can lay down rules on deposit and refund schemes and its
management for collection, recycling and deposit of products with further take back obligations
for manufacturers, importers and dealers. The statutory Order NO. 299 of 30th April 1997 on
Waste contains the definition of hazardous and non-hazardous waste (waste catalogue), the
definition of the procedure for transport of waste, the requirements/obligations regarding

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60 The analysis is based on Scharff (1999) and personal communications from Org-Consult.
information and documentation, and collection schemes. New legislation is planned on glass-recycling (including automotive glass), the use and disposal of PVC, including that contained in cars.

After many-years debate, the Environmental Premiums Act No.372 of June 1999 addresses ELV. The new legislation will be into force not later than 01.07.2000. The act includes adaptations of the Environmental Protection Act, a specific decree on ELVs, and a law on environmental charges for cars. All companies treating waste should be subject to certification based on ISO standards and ELV will be the first sector subject to this obligation. The specific decree on ELV will reflect the indication by industries (dismantling and recycling) and will have provisions similar to the EU Directive. It will include an authorisation system conditional to certification. The mechanism for financing ELV treatment will be based on a fee of 12 EUROs per year charged on car owners for the entire life of the car. The fees will be collected by an independent foundation managing the scheme. The last owner of an ELV will have to deliver to authorised dismantlers and it will have to pay for ELV treatment, but he/she will receive a lump-sum reimbursement when presenting the certificate of destruction to the foundation managing the scheme. The reimbursement could be between 160-200 EUROs and should be greater than the estimated costs incurred in delivering ELV to the dismantler (Scharff 1999).

II.7.4. Finland

The estimated number of ELVs in Finland was 110,000 in 1997. The average age of ELVs was 18 years and the market value was positive on average (up to 25 EUROs). There are 40-50 dismantlers with legal permission and 100 scrap dealers operating in Finland. They collect ELVs mainly for used spare-parts. The dismantling degree of ELVs is limited by the high average age of ELVs. About 2,150 small scrap traders collecting ELVs and other metal scraps for delivery to the shredder companies are also operating. In most cases, they are illegal and works without a licence. There are in total 3 shredders in Finland which are all owned by the Kuusakoski Oy Group, the largest collector and processor of scrap and multi-metal waste in Finland. Car-batteries are collected by shredders and then exported to Sweden for lead recycling.

The legal framework for ELVs is based on the Waste Management Act of 1994, which is based on EU waste-legislation. It contains the prohibition of landfilling ELVs by last owner and the prohibition of landfilling tyres. Tyres have to be recovered either by material recycling or energy recovery. Tyre manufacturer/importer have to pay for each passenger-car-tyre a recycling-fee of 1,6 EUROs to a fund (other type of tyres have to fulfil different conditions). Car importers have to pay the tyre-fund-system 8 EUROs for each car (legislation was introduced in 1996). According to the hazardous waste act (which also address batteries), the producer of hazardous waste has the responsibility for its products, but car importers has no obligation for car batteries and there is not recycling fee or environmental tax on batteries. ELV is also considered in the

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61 The analysis is largely based on personal communications from Org-Consult.
act regarding the “wrongly parked cars” that imposes the last owner to assure recycling of ELV. In the case of illegal dumped cars, the municipal police can assure the recycling and charge the expenditures to the last owner (if known).

The Finnish Government is preparing a legislation to make car manufactures and importers responsible for ELVs. The basis will be the objectives and instruments of the draft EU Directive, including free take back and the targets for re-use/recovery/recycling. When the Directive will be adopted, its provisions will be introduced in the Waste Management Act of 1996. At present, however, there are not specific requirements on industries. There are not plans for voluntary agreements by car importers/producers.

II.7.5. Greece

The estimated number of ELVs was 50,000 in 1996/1997. The average age of ELVs was 20 years with an average age of the car stock of 12 years. In general, ELVs have a negative market value. Dismantlers strip car for valuable spare-parts and then pass the stripped car to shredders. Environmental standards of dismantlers are usually low and there is lack of adequate draining.

The legal framework for ELV is mainly the general Waste Management Law. The disposal of ELVs is under the jurisdiction of local authorities that should assure de-pollution of the ELV, the recycling of components (e.g. batteries) and the disposal of other waste on the basis of the general waste management law. There is not specific legislation on ELV but it is expected in 1-2 years in accordance with the EU Directive. There is not specific legislation on the recycling of oils, batteries, and tyres.

In 1991 and 1992 there was a State program for old-car scrapping based on a premium of about 1,000 ECU's. The Greece MOT released a certificate when the ELV had been dismantled by a “legal” dismantler. This certificate enabled the dismantler to receive the premium from the state. A new state program is in preparation (by support through AMVIR) for end of 1999. Car dealers are storing ELVs at present to recycle them when the program enters into force to receive the premiums.

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62 The analysis is mainly based on personal communications by Org-Consult.
II.7.6. Ireland

Estimated number of ELVs was 85,000 in 1997 with an average age of 12-14 years. The market value of ELVs is generally negative. However, many ELVs are delivered to shredder companies without de-polluting. Shredder pays a positive price for wrecks to dismantlers. Shredder residue is generally landfilled and no incineration is occurring at present. About 18% of ELV-tyres is used in the farming sector (ground material in silage pits).

A scrapping scheme has been introduced by the Government from July 1995 to 1997. A premium of 1,270 EUROs was paid to the last owner for the scrapping of his old car and when a new car was bought. About 65,000 vehicles (passenger cars) have been scrapped under this scheme.

The relevant legal framework is based on Waste Management Act 1996, which came into force on May 1998. A significant number of regulations have been produced under the act, such as the obligation to recycle oil and batteries through certified companies. A new legislation for the recycling of batteries is in process (on the basis of the EU battery directive), which will extend the scope of present regulations (including the requirements for batteries in cars). Waste Management (Permit) Regulations of 1998 define activities subject to waste permit and they include: incineration of waste; recovery of scrap metal or other metal waste; dismantling or recovery of vehicles; recovery of waste which is composed of or contains mercury or its compounds (including electric lamps, light bulbs and fluorescent tubes). Under the Waste Management Act it is necessary to remove waste oils and batteries dismantlers receive permits by local authorities and they have the obligation to remove and recycle of oils and batteries out of ELVs (batteries are removed in 95% of ELVs). The legal requirements (and future EU requirements) are estimated to cost 51-64 EUROs by the dismantlers association.

There is not a specific regulation for ELVs but it is in preparation in accordance to EU Directive in combination with a voluntary agreement. The Irish Government is in favour of the Dutch system (fund system). It might be possible that the government will put in force obligations more demanding than the Council Common Position, in particular in terms of recycling targets. The Society of the Irish Motor Industry will present its proposal in November 1999.

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63 The analysis is mainly based on personal communications by Org-Consult.
II.7.7. Portugal

The estimated number of ELVs in 1997 was 120,000 units. The average age was 15-17 and the market value was positive on average (around 40 EUROs). The dismantling industry in Portugal is poorly organised. There are only 4-5 companies with a business concentrated in the disposal/dismantling of ELVs and recovery of used spare-parts. There are many scrap collectors, usually working under poor environmental standards, that store ELVs and take out some used-parts. De-pollution of ELVs is usually very lacking except sometimes for oils and batteries. Shredding occurs of partly crushed/pressed ELVs for metal recovery. There are three projects, financed by the government, for tyre recycling as an alternative to landfill. The company Biosafe, in partnership with an American company, received financial aid to build up a tyre-granulation plant, and it is planned to export the granulated rubber to the United States.

The relevant legal framework for ELVs is that on waste management, and in particular the Decree 268/98 (recycling of scrap), the Decree 39/97 (general waste management law), the Decree 961/98 (recycling and waste management), the Decree 03/94 (waste catalogue), and Poteria 961/98 (legislation for authorisation of dismantling facilities, mainly addressing internal requirements). There is not specific legislation on ELV, although it is expected.

A voluntary agreement between government and the ELV industries was signed on June 2nd, 1999. It is very similar to the Spanish voluntary agreement. A Standing Committee has been set-up to ensure the execution of the agreement.

The participants to the agreement are the Ministry of the Environment, ACAP, ANAREPRE, ANECRA, NAT/AIP, ACP.

The targets of the agreement are:

- Reduction of ELV waste disposed off to 15% of the vehicle’s total weight in 2005;
- Reduction of ELV waste disposed off to 5% of the vehicle’s total weight in 2015;
- Targets of the EU Directive on ELVs will be adopted, if different.

The take back of ELVs occurs at market conditions.

The commitments by car manufacturers/assemblers, importers and components manufacturers are:

- to increase Research and Development (with the support of public authorities) in order to produce and incorporate parts increasingly valuable for recycling and increase the amounts of recycled materials in the vehicles;
- to increase the recovery rate of a vehicle through appropriate design;

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64 The analysis is based on AIP et al. (1999) and personal communications from Org-Consult.
to provide technical data to ensure that the recovery is made under the best technical, economic and environmental conditions; this data shall be made available by 31st December 1999 (date can change by the decision on the EU directive draft);

to contribute (e.g. formal contract, foundation of a technical group) to the efforts of recovery;

to intensify the co-operation between manufacturers and equipment suppliers (including at EU level);

to provide a guarantee against manufacturing flaws in vehicle parts/components.

The commitments by operators in the dismantling, material recovery and energy recovery industries are:

- to complete treatment of ELVs (on the basis of legal requirements, within economically viable environmental requirements) and ship any remaining products/waste to operators in the downstream operations;
- to accept discharged vehicles (e.g. coming from entry points);
- cancelling the licence number at the Direccao Geral de Viacao;
- to join a technical group assessing the technical and economical feasibility of recovering materials from ELVs;
- to intensify R&D on recovery efficiency; dissemination of information
- to prepare specifications setting out the conditions to be observed when transferring materials between operators
- to provide data needed, e.g. to quantify the flow of ELVs and materials form them.

The commitments by material producers are:

- to intensify the communication with the market participants (establishing a technical relationship and join the technical group);
- to encourage R&D so as to improve material valorisation techniques;
- non-metals producers must take part in the valorisation of materials produced by the recycling sector.

The commitments by the car dealers and traders are:

- to pass on ELVs only to authorised dismantlers;
- to ensure proper management of waste resulting from vehicle repair;
- to promote the dismantling of ELVs by authorised dismantlers.

Public authorities have the role of setting up the legal framework, such as

- the procedure for issuing a certification of destruction,
- to ensure de-registration of ELVs,
- to authorise only operators who meet the minimum of the environmental and technical requirements (as specified in the voluntary agreement);
- to promote the dismantling of ELVs;
- to prevent ELVs being dumped;
- to support Research and Development.

The Standing Committee of the agreement has the following tasks:
- re-examination of the quantitative recovery targets;
- promotion and continuous assessment of economic and technological developments in the sectors
- co-ordination of actions on the nation level;
- data collection, processing and transmission in regard to this system;
- to prepare a report on the state of ELVs in Portugal and draft a program of legislative and operational actions, such as:
  - by 30th September 1999 set up a body to co-ordinate the flow of ELVs;
  - by 31st December begin the certification of collectors and dismantlers and to give opinion on technical/procedure requirements;
  - to provide information to last owner about legal duties (e. g. de-registration)
  - to ensure by 31st December 2000 that no ELV is destroyed or exported without de-registration;
  - to establish standardised records for vehicle-repair waste management.
II.7.8. Spain

The estimated number of ELVs in Spain in 1997 was 550,000 units. The average age was 14-15 years and the market value was positive on average (up to 30,000 Pts). Between 2,000 and 3,500 companies are operating in the dismantling sector. Companies with mobile compactors (crushers) connect the dismantlers with the shredding companies (collection, compaction and transport to shredder). The environmental protection standards of dismantlers in Spain are very low. Only a few dismantlers can assure a complete draining of ELVs.

Some project on ELV treatment developed during the last few years. The Project RECICLAUTO Navarra S.L., to which Volkswagen participates, has the main objective to organise a nation-wide system of draining and cleaning ELVs at the stage of dismantling according to ecological standards. The dismantler has to pay the draining (15,000 Pts) and the costs to receive the car form the last owner (5,000 Pts). REYFRA is a project between ANAFC and some shredders aimed at investigating the necessary equipment of dismantlers and shredder companies, in order to achieve a high recycling rate of ELVs. ANFAC also started to analyse the possibilities of energy recovery of shredder residues in 1999.

The legal framework for ELVs is mainly based on general waste law, and in particular the Waste Management Act of April 1998. There is not a specific regulation on ELVs. A national decree is under preparation in accordance with EU-directive (with preference for a fund system). ANAFC, representing the car industry, is opposing a FTB solution, even though the FTB effects could be limited by the positive market value of ELVs. Regional and city authorities are responsible for abandoned cars.

From 1994 to 1997, programmes of incentives for scrapping old cars have been introduced in Spain. In the RENOVE I and II programmes (1994 and 1995), the scrapping premium took the form of a tax reduction. The PREVER programme (Programa Estructural para la Renovaice de Vehiculos), introduced in April 1997, includes a scrapping premium of 80,000 Pts paid by the State for a new car which is substituted for an old car (at least 10 years old) to be disposed off. The new car must be registered 6 month after the old car has been de-registered.

A voluntary agreement on ELV was signed in June 1996 covering the period until 2000.

The leading principles are similar to the French Accord Cadre, and recycling activities should develop under free market conditions. The participants are the Ministries of Environment, Industry and Energy, ANFAC, ANIACAM, AEDRA, SERNAUTO, FER, FERMA, UNESPA, FACONAUTO.

The targets of the agreement are:

- Reduction of waste disposed off to a maximum 15% of the vehicle’s total weight in 2002;
- Reduction of waste disposed off to a maximum 5% of the vehicle’s total weight in 2015.

The commitments of car manufacturers/importers and manufacturer of components are:

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65 The analysis is based on ANFAC et al. (1996) and personal communication by Org-Consult.
To intensify R&D activities to produce and use more recyclable components and materials;

To produce homogenous components;

To intensify co-operation within the car manufacturers and between suppliers;

To make dismantling manuals available.

The commitments of the car dismantling and shredding industry are:

- to increase the technological and environmental standards of ELVs draining;
- to intensify material recycling activities (according to present technological, ecological and economic possibilities);
- to document the treatment of ELVs and material flows.

The commitments of the material manufacturers are:

- to intensify the communication with the market participants;
- to increase the value of materials for recycling (e.g. plastics).

The commitments of the car dealers are:

- To deliver ELVs only to authorised dismantlers;
- To promote the dismantling of ELVs by authorised dismantlers.
II.7.9. Norway

The estimated number of ELVs was 115,000 in 1996/1997. The average age of ELVs was 17 years. A system of FTB is in force including a premium to last-owner for delivery of ELV. The dismantler receives a lump sum and an additional reimbursement, which depends on the price of metal scrap. The ELV has to be drained (waste oils) and batteries and tyres must be dismantled. Fluids have to be treated as hazardous wastes.

The legal framework for ELVs is based on the General Waste Act, the legislation on batteries, and hazardous waste legislation. An “environmental levy” on car imports (tax regulation) with free-take-back of ELVs for last owner is in force. Since January 1st, 1999, car importers pay a tax of 145 Euro (1,200 NOK) per vehicle (disposal charge), which is paid to a fund administrated by the State. The last owner receives 180 Euro (1,500 NOK) from the fund when he/she delivers his/her ELV to a dismantler. There are not recycling/recovery targets in force. In 1996, the State paid an extra “scrapping premium” of 570 EUROs, so that the last owner received in total 685 EUROs for the scrapping of his ELV. During the time of the extra premium 106,000 passenger cars and 44,000 vans have been scrapped. The dismantler receives financial aid for the free take back obligation and treatment of ELVs. A voluntary agreement is not planned.

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66 The analysis is mainly based on personal communications by Org-Consult.
II.8. United States

II.8.1. The ELV problem

Approximately 10 - 11 million ELVs arise each year in the United States. The main method of dealing with ELV involves dismantling, shredding, and recycling of steel and non-ferrous metals. Dismantlers remove high-value parts for reuse and reconditioning. Shredders recover ferrous and non-ferrous metals, which are sent to recyclers. Recycling rate is approximately 75% of the vehicle by weight. The remaining 25% (ASR or fluff) is composed primarily of plastics and fibres. About 2.5 to 3.0 million tons of ASR are disposed of in landfills each year. About 94% of the cars and trucks at the end of their useful lives are currently returned to dismantling and shredding facilities.

There are not general restrictions on landfilling of ASR in the United States, and ASR is generally classified as non-hazardous waste. Increasingly stringent regulations for municipal solid waste landfills have increased ASR disposal costs while reducing landfill capacity. Furthermore, ASR has, in some cases, failed the toxicity test for hazardous waste due to heavy metal contamination. California has classified ASR as hazardous waste. Hazardous waste designation increases ASR disposal costs by requiring management in licensed hazardous waste facilities.

Car manufacturers have introduced more plastics materials to reduce vehicle weight for fuel efficiency. This has increased the percentage of ASR from shredders. Plastics content in an average vehicle in the U.S. increased nearly 50% between 1976 and 1992. With the steady reduction in readily recoverable metals combined with increasing landfill costs for ASR, the economic viability of the automobile shredder industry could be threatened.

II.8.2. Regulation attempts

The U.S. House of Representatives proposed legislation in 1991 that was considered by the car industry as the forerunner of mandatory recycling. The Automobile Recycling Study Act of 1991 was introduced but did not pass and was not reintroduced in subsequent Congresses. Included in the findings of the bill was the statement that automobile manufacturers must work in tandem with the producers of raw materials for automobiles, materials suppliers, the automotive dismantling industry, the scrap processing industry, chemical process engineers, and the recycling industry to develop a more recyclable automobile. The bill would have required a study by the EPA, in cooperation with the Department of Transportation and the Department of Commerce, on the potential for increased recycling of automobile components in the U.S. and the steps needed to increase recycling. The study would have included “methods for incorporating recyclability into the planning, design, and manufacturing of new automobiles” and

The analysis is largely based on Davis et al. (1997), EPA (1997 and 1998), IPTS-JRC (1996), and direct information on waste prevention programmes collected at EPA in 1997.
the “feasibility of establishing design standards for automobiles that would result in a gradual phase-out of hazardous and non-recyclable materials used in automobiles.”

The development of ELV regulations and policies in Europe can be considered another factor that stimulated the industrial responses in the U.S in recent years.

**II.8.3. Industrial initiatives**

The industrial responses to ELV have been in four main directions. Firstly, U.S. companies are preparing to comply with European regulations in their European manufacturing and sales operations. Secondly, they are “importing” some of their experiences in Europe on increased car recycling. Thirdly, they are attempting to prevent a specific regulation in the U.S. by demonstrating voluntary progress in car recycling. Fourthly, they are responding to competitive marketing pressures from European manufacturers in an U.S. market that is anticipated to stress recycling as a market attribute in the future.

One cooperative response from the U.S. industry was the creation of the Vehicle Recycling Partnership (VRP) in 1991 to promote and conduct research required for the technology to recover, reuse, and dispose of materials from scrap cars. The VRP is currently part of the United States Council for Automotive Research (USCAR), formed by GM, Ford, and Chrysler in 1992 to strengthen the technology base of the domestic car industry through pre-competitive research.

The objectives of the VRP are: to understand issues involved with vehicle recycling; interact with other researchers; conduct research and development of technologies and methods to recycle materials and components from scrap cars; and develop guidelines for design and material selection to facilitate recycling. Two main goals of the VRP are to develop recycling technologies to reduce ASR and to support research into recovery of non-metallic materials from ELVs. The VRP is composed by three working groups: (1) disassembly; (2) shredder residue; (3) design guidelines. One major project of the VRP is the Vehicle Recycling Development Center, established in 1993 as the first Big Three joint research facility. The Center works on car dismantling and addresses in particular fluid removal and recycling, economic analysis, polymers identification, seat and foam recycling, glass recycling, carpet and interior trim recycling, and instrument panel and bumper recycling. The VRP is working with the American Plastics Council on developing pyrolysis technology to decompose plastic wastes to a hydrocarbon gas and oil that can be used as a feedstock to produce new plastics.

Various other programmes on car recycling and LCA are being carried out by U.S. car companies and component producers. The United States Automobile Materials Partnership (USAMP) addresses life-cycle and include the three major automotive material producers in a partnership aimed at evaluating materials (steel, aluminium, and plastics) for car production. The project is developing a LCA database and is aimed at developing a complete life-cycle inventory of vehicles, a database on processes in the automobile system, and a computer modelling capability. The Cadillac Division of GM is developing a model on Intelligent Material Selection System that incorporates life-cycle evaluation of materials together with traditional cost analysis.
Chrysler Corporation is developing a program on life-cycle management, which is focused on hazardous materials. Other initiatives on LCA are being carried out by the University of Michigan and the Argonne National Laboratory. All the U.S. car manufacturers have developed lists of restrictions on materials that are used as specifications for their suppliers. In the framework of the Common Sense Initiative and in cooperation with the University of Tennessee, EPA developed a specific activity on automobile manufacturing that is focused LCA analysis.

II.8.4. Company-level experiences

Two major experience in ELV recovery in the U.S. have been developed by Ford Motor Company for bumpers' recycling of and by GM for post-consumer plastic-parts recycling. 68

Ford Motor Company

The Manufacturing Environmental Leadership Strategy of Ford Motor Company contains goals reflecting a commitment to Extended Product Responsibility and includes:

- Ford’s Substance Use Restrictions, which specify substances to be restricted in or excluded from parts and materials supplied to Ford;
- Ford’s Worldwide Recycling Guidelines to increase the use of recycled content and the recyclability of the materials used in the automobile;
- an across-the-board target by Ford to achieve a minimum 25 percent post-consumer recycled content of the plastic materials used in Ford cars. 69

The Ford take-back and recycling program for bumpers has evolved from partnerships between Ford and GE Plastics, and between Ford and American Commodities, as well as a network of automotive dismantlers. Ford started its bumper recycling program in the U.S. in 1993 as a pilot program to recycle plastic bumper material into tail light housings. Currently, the program is recycling bumper material back into bumpers. Since 1986 most Ford bumpers have been made of Xenoy resin, an engineered plastic which is a blend of polyester and polycarbonate resins.

In the pilot program GE Plastics took post-consumer Ford Xenoy bumpers from Ford dealers and bumper shops and from automobile dismantlers, and supplied them to a plastics recycler, Recycling Separation Technologies, Inc. The purified regrind was sent back to GE Plastics, which recomounded it and sold it to Ford for reuse. Ford also began a partnership in 1992 with American Commodities, Inc., a plastics recycler. American Commodities reprocesses post-use bumpers into compounds called Enviralloy, which Ford reuses in new automobile parts, using proprietary technologies to remove up to 99.7 percent of paint residue.

68 See Davis et al (1997) for more details.
69 See also the analysis on Germany in Par. II.2.
In order to collect bumpers, American Commodities has developed a network of 400 dismantlers across the country and has provided them with a written specification on methodologies for dismantling and product identification. The company pays dismantlers $4.00 each for the bumpers and has 25 - 30 regional collection points for transport of the bumpers to the recycling plant.

The bumper recycling program currently recycles bumper material into new bumpers and is recycling approximately 1.5 million pounds of Xenoy plastic per year. American Commodities collects and recycles more Ford bumper material than is currently reused by Ford. The company is currently recycling 6-8 million pounds per year and sells the recycled material Ford does not use to other manufacturers. The material is sold at a 25-30% cost savings as compared to virgin Xenoy.

Ford found that greater cost savings were achieved in recycling bumper materials back to bumpers, instead of tail light housings. Benefits to Ford include:

- costs saving: Ford estimates that it will save about $1 million per year with the bumper recycling program;
- demonstration of Ford commitment to environmental protection and to its recycling goals, which provide corporate image and marketing benefits;
- increased recycling as evidence that potentially costly take-back and recycling regulation for cars are unnecessary in the U.S.;
- reduction of the total numbers of plastic resins used in the car through cascade recycling (reusing higher-quality materials in lower-quality applications).

The bumper recycling program at Ford represents approximately 125,000 bumpers per year that are being diverted from the ASR landfill. In addition, American Commodities is diverting approximately 300,000 more bumpers per year.

One technical barrier to the program was the difficulty in removing paint and other materials from the plastic material to be recovered. Economic barriers stem partly from this technical barrier and partly from the lack of an established infrastructure for getting the bumpers from dismantlers to recyclers. The main regulatory barrier to the bumper recycling program has been the crash worthiness standard that requires extensive testing of recycled material to determine whether it performs as well as virgin material. For this reason, Ford chose initially to utilise only 25% recycled content in parts that are integral to impact absorption. Even with the limited recycled content used in impact-absorbing parts, Ford tested five times as many bumpers to demonstrate compliance with the crash worthiness standard than it would normally test for virgin material. GE felt that it would be potentially more difficult to control the quality of the recycled material for this critical application. Ford designers were concerned about any changes in material quality that might affect the performance of the bumpers.

The success of the program depends from the willingness of auto dismantlers and recyclers to remove and clean the bumpers in a manner that facilitates recycling while being economically
attractive to the dismantler. The partnership between American Commodities and dismantlers would have been more difficult for larger companies, like GE or Ford, to develop directly.

**General Motors**

General Motors has acknowledged Extended Product Responsibility in its corporate Environmental Principles. GM has also adopted the principles put forward by the Coalition for Environmentally Responsible Economies (CERES), a coalition of investors, public pension trustees, foundations, labour unions, and environmental, religious and public interest groups.

GM has adopted hazardous substances restrictions for materials' suppliers and has developed recycling guidelines used in the design and supplier-selection processes. GM also has an innovative relationship with its chemical suppliers where manufacturing facilities enter into “chemical management” contracts in which suppliers receive a fee based on GM production levels, not based on volume of chemicals used.

Saturn Corporation, a subsidiary of General Motors, has been one of the first U.S. auto manufacturers to begin a recycling program for post-consumer plastic parts. This program involves a take-back system from Saturn body shops for damaged parts. Saturn uses TPO (thermoplastic olefins) in the front and rear facia (bumpers) for its automobiles. The facia are painted during the painting of the automobile. Painted plastics can be recycled by blending in with like material for non-appearance applications such as wheel liners.

In 1993 Saturn started a pilot program for taking back post-consumer bumpers from body repairs through Saturn retailers. A full-scale program for collecting bumpers from all of the 340 Saturn retailers began in December 1994. The retailers collect damaged bumpers from Saturn body shops, which are typically independent companies. The parts are returned to the Saturn plant at Saturn expense and constitute the major expense of the Saturn program. At this point, American Commodities takes ownership of the bumpers. There, any brackets, headlamps, reflectors and bumpers stickers are removed, and the facia are ground before transport to a recycling facility. The American Commodities facility removes the paint and re-extrudes and pelletizes the plastics and sells the recycled resins to manufacturers.

The Saturn program is currently collecting approximately 15 bumpers per day and the program represents a diversion of approximately 47,000 pounds per year of plastic from landfill disposal. This quantity of bumpers, however, represents only about ten percent of the new bumpers being shipped to retailers for repairs to Saturn cars. With 18 pounds of plastic in the front and rear bumpers and over one million Saturns on the road, the potential diversion from disposal could be much more significant.

The recycled material from American Commodities is not directly incorporated back into new Saturns. Saturn has plans to recycle the post-consumer painted bumpers taken back in the Cadillac Division of GM. The bumpers will be ground at or near the Saturn plant, and the ground plastic will be shipped to the molder of wheel wells for the Cadillac plant. This “in-house”
recycling will increase the value of the scrap, minimise shipping costs, and provide the benefit of cost savings.

The benefits to Saturn of the current bumper recycling program include avoided land disposal costs for Saturn repair shops. Once the bumpers are recycled into wheel wells for new Cadillacs, GM will also benefit from reduced material costs for the production of wheel wells, and Saturn will receive a higher return on the sale of the recycled material. Product design changes have not been necessary to facilitate facia take back and recycling, because the bumpers are readily removed from the car and are made of an easily recycled material. As Saturn focuses more on post-consumer recycling, however, it expects to facilitate the disassembly of components through necessary design changes and to consolidate materials to reduce materials diversity.

The principal technical barrier for the program, as with the Ford program, has been the removal of paint and contaminants from the scrap bumpers. While Saturn’s approach to taking back bumpers from its retailers and repair shops is innovative and efficient, the company has not yet tackled the infrastructure for retrieving bumpers from automobile dismantlers. This institutional barrier may be overcome by the partnership with American Commodities and its dismantler network.

**Emerging suggestions on innovation**

The bumper recycling programs at Ford and Saturn represent extended product responsibility because the manufacturers of automobiles have assumed more responsibility for managing materials from end-of-life vehicles. In the case of Ford, the program also demonstrated shared responsibility by the material supplier, GE Plastics. Both Ford and Saturn have partnered with the recycler, American Commodities, with the aim of creating both the supply of and demand for the recycled bumper material. By taking back the bumpers, they have shifted the physical and economic responsibility for managing some of the components of auto shredder residue from the shredders to themselves.

Both programs at this early stage are only recycling a small percentage of end-of-life bumpers available for recycling. The higher amounts of bumpers being recycled in the Ford program are partly indicative of the greater number of end-of-life bumpers available, but also indicative of a program that created a steady demand for the recycled material before collecting it. The automobile industry, with its large demand for plastics, can create a closed-loop demand for recycled plastics. Both the Ford and Saturn programs dealt with technology requirements for recycling painted plant scrap before dealing with the more difficult problems of end-of-life parts.

The extent to which the two companies created life-cycle partnerships in the bumper recycling programs differed. The Saturn program had no parallel to the Ford/GE Plastics partnership. Both programs also demonstrate the importance of economics for voluntary EPR initiatives. While attention to ELV recycling in the U.S. is at least partly being driven by the desire to avoid a regulatory approach, economic aspects matter to the companies involved. Given the costs of dismantling, sorting, collecting, transporting, and cleaning plastic parts for recycling, economic
balances are only positive for high-value plastics in large parts that are readily disassembled. The economic balance is also more positive when the recycled material can directly substitute for a similar high-value virgin material, instead of a lower-value virgin material.
II.9. Japan

The number of ELVs in Japan is estimated at 5 million units per years. The recovery rate is about 75% and the amount of (landfilled) ASR is estimated at 800,000 tons per year. The ELV treatment operations are performed by an estimated number of 3,500-5,000 dismantlers. The dismantling sector is considered to be not well-organised and non-appropriate treatment is considered to have adverse environmental impacts. Shredding companies are 140. The possibility of disposing-off ASR by landfilling is decreasing as landfill capacity is expected to be depleted by 2008, landfill costs are rapidly increasing, and illegal dumping occurs.

There is not a specific regulation on ELV but various laws create a framework for ELV management. The Environmental Law of 1994 includes the objectives of waste reduction, reuse of end-of-life products, promotion of recovery and recycling, and appropriate waste processing. The Waste Disposal Law revised in 1997 introduced heavier sanctions on inappropriate waste management and additional tasks for regional governments. Guidelines on waste processing and recycling were issues in 1997 following the Recycling Law of 1991 and they address the role of relevant social actors introducing waste recycling targets. The Recycling Law specifically addressed waste from car and other durables but with weak obligations.

In 1997, the Japanese car industry launched the ELV Recycling Initiative which is based on voluntary action plans by the industries in the ELV chain (the Government, dealers, manufacturers, dismantlers, shredders).

The objective of the Recycling Initiatives is to promote car recycling without the introduction of a new specific regulation on ELV. With the aim to reduce the demand of landfills for ASR and clean the waste stream from ELVs, quantified targets for ELV recovery are established and innovation in car design are pursued. The organisational approach is based on the definition of tasks to be distributed among the various industrial actors as well as car users. The parties involved in the Recycling Initiative are: MITI (ministry of International Trade and Industry), JAMA (Japan Automobile Manufacturers Association), the Japan Auto Parts Industry Association, the Japan Automobile Dealers Association, the Japan Automobile Importers Association, the Japan Car Maintenance Promotion Federation, the Japan Subcompact Car Association, the Japan Used Car Dealers Association, the associations of dismantlers, and the Japan Steel Recycling Industry Association.

The Recycling Initiative adopted the following targets:

- for the car industry: achievement of a recyclability rate of new vehicles at no less than 90% by 2002; reduction of lead content in new vehicles to less than 50% of 1996 level by 2000, and to less than 33% of 1996 level by 2005 (batteries excluded);

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70 The analysis is mainly based on JAMA (1999), IPTS-JRC (1996), and personal communications from Fumikazu Yoshida, Hokkaido University.
• for the other industrial partners: reuse/recovery rate of ELVs at no less than 85% by 2002 with ASR to landfill reduced at 3/5 of 1996 level by the same date; reuse/recovery at no less than 95% by 2015 with ASR to landfill reduced at 1/5 of 1996 level by the same date.

The action plans related to the Recycling Initiative are at two levels: (a) the JAMA action plan; (b) the member companies action plans.

The JAMA Action Plan is mainly addresses the improvement of new car model recyclability and the reduction of their environmental impacts. The objectives are: (a) to define guidelines for the assessment of vehicles at the design stage; (b) to define guidelines for the calculation of recyclability of new models; (c) to reduce the lead content in new vehicles with a priority to specific parts; (d) to facilitate air-bag dismantling and disposal. The actions for vehicles currently in use and production include: (a) information dissemination about dismantling and materials contained in cars; (b) dissemination of information on appropriate disposal of ASR; (c) improved processing of parts and materials with the aim of dismantling/recycling; (d) increased use of recycled materials from ELV and other products in car production; (e) increased use of recycled materials from ELVs in other applications. The plan includes cooperation with other industries working on ASR recovery and parts, as well as materials manufacturers involved in recycling operations. Cooperation with dismantlers for the treatment of ELVs and industries recovering air-bags and CFCs, is also pursued.

The development of plans by individual manufacturers started in 1998. They are based on the quantified targets described above and include: (a) technical developments on dismantling; (b) assistance to dismantlers; (c) preparation of dismantling manuals; (d) research on reuse of parts from ELVs; (e) technical research on energy recovery from ASR.

The action by car manufacturers on DFD and DFR started before the 1997-98 action plans. Nissan and Toyota have been among the first carmakers to make marking of parts, to reduce the number of plastics, to use mono-material parts instead of composites, to use recycled materials in car parts. Toyota also tried to automate dismantling operations.

The future direction of action by Japanese carmakers are towards the standardisation of recyclability calculations, the reduction of recycling costs, the development of ASR energy recovery to overcome the limitations of material recycling, and the identification of appropriate cost distribution among industrial actors.

Japanese carmakers are also exploring the implications that the developments of EU regulations on ELV can have on their operations in Europe and they are already taking actions to face their foreseen obligations and costs.
PART III

THE INNOVATION PROCESS AND
THE ROLE OF REGULATION

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III.1. Introduction

A broad perspective to the definition of both innovation and regulation must be taken for ELV as well as other areas of environmental regulation-innovation analysis (see Hemmelskamp and Leone 1998, Kemp 1997, Kemp et al. 1999, Zoboli 1998).

The complex organisational changes taking place in downstream treatment and recycling operation for old cars suggests considering organisational changes as essential components of ELV innovation. The involvement of different industrial actors in the ELV problem suggests taking a systemic view of innovation as an inter-industry issue. The time requirements and capability-creation features emerging of ELV innovation suggested considering innovation as a process. These methodological choices also reflect recent contributions addressing the analytical limitations arising from addressing innovation as defined only by “technological” innovation possibly measurable by specific indicators, e.g. patents and R&D expenses. Innovation can be instead defined as a capability-knowledge process in a systemic framework (see, for example, De Liso and Metcalfe 1996, Dosi et al. 1988, Edquist 1997, Lundvall 1992).

The features of ELV regulations, especially at the EU level, as complex packages including technical regulations, economic instruments, links with other waste and/or industrial regulations, and the coexistence of specific legislation with voluntary agreements, suggested to consider ELV regulation in the broader sense of “policy”.

By adopting this perspective, the case of ELV can highlight significant features of the policy-induced innovation mechanism and it can supply suggestions about appropriate environmental policy making in complex techno-economic systems.

On the basis of the evidence emerging from Part I and Part II, we shall analyse the ELV innovation process and the role of regulation at five levels.

- The identification of specific innovations —still at different degrees of development, from R&D to practical implementation— occurring in the automobile and other industries to address the ELV issue. The analysis will address the main developments emerging from country-level analysis of Part II. A detailed examination of some innovations is presented in the “Technical Analyses” of this Report.

- The definition of the systemic features of the innovation process. The latter involves interrelated changes by different industrial and economic actors, and can be thought as a learning process that is differentiated between the different companies and the different national contexts. The targeted nature of the innovation process, i.e. policy-established and/or self-imposed quantitative targets for reuse/recycling/recovery, gives rise to different feasible innovation paths. The latter involve the different actors and specific innovations to a different extent, and can be pursued as alternative or complementary responses.

- The interpretation of the observed interactions between policy-making and innovation (or between policy makers and industries) from the point of view of their respective reference principles and the use of knowledge. The controversial nature of the ELV issue can be
partly explained by the existence of different conceptions about the “best policy” rather than as a conflict between economic self-interest and environment preservation.

- The possibly critical role of policy targets as a “focusing device” and specific policy instruments as a “selection device”. Despite the difficulties of defining the role of specific instruments when they are part of complex policy packages – as the EU Directive proposal(s) – some instruments can have critical significance by inducing and/or forcing industrial actors to pursue specific innovation path(s). A great deal of uncertainty is associated to ex post impacts of instruments. Actual results might differ from those expected so that the prevailing innovation path(s) may not be the policy-desired one.

- The cost-benefit implications of regulation when the latter involves open and uncertain innovation process. Starting from the still very limited evaluation effort made by both policy-making and industry, some limitations and opportunities for evaluation will be suggested when cost-benefit distribution matters for induced-innovation. Competitiveness and competition implications of ELV regulation will be considered in this cost-benefit framework.

### III.2 Specific innovations

#### III.2.1. Recycling departments and competencies

Between end-1980s and early-1990s, major European car producers (BMW, Daimler, FIAT, Ford, PSA, Renault, Rover, Volkswagen, Volvo) created internal functions, generally belonging to the environmental departments, addressing ELV and recycling. By being the reference for the two main innovation directions, i.e. downstream operations and car design, they have the features of a crossroads between heterogeneous tasks and competencies. They manage the relationships with other industries, e.g. dismantlers, in the framework of covenants and VAs (if any), they manage the R&D experiences and the pilot projects of the company (e.g. dismantling pilot plants), and they interact with other companies and institutions for the co-operative research efforts on ELV. In many cases, they interact directly with material and component suppliers for technical issues, and have a role in car design by co-operating with the other functions and departments for the development of design for dismantling (DFD), design for recycling (DFR), and LCA. They are also the link with other carmakers for information exchanges and actions at the policy-making level. The significance attributed to these departments is uneven in the different companies, also depending on the different role the latter attach to ELV and recyclability. In all car companies, however, they represent the creation of functionally specialised competencies and skills not existing before in a structured form. With the development of ELV management experiences and the perception of recycling as increasingly important for car making, they assume a role of increasingly general significance for the company.
III.2.2. Dismantling and recovery networks

Traditionally, carmakers did not have significant connections with post-consumer operations as dismantling and recovery of ELVs. The only link was through the spare parts markets where a mixed picture of competition and complementarity between new and old spare-parts markets did prevail (see Part I). From the experiences examined in Part II, the creation of networks of dismantlers linked to individual car companies is one of the main directions of organisational innovation.

The form of co-operation varies between different companies and countries, especially in terms of the actors taking the co-ordinating role. The latter are often the car industry and the shredding industry together, as in France and partly in Germany, but in other cases the co-ordinator is mainly the car company, as in Italy and Sweden. The specific contractual arrangements between the industrial actors (i.e. carmakers, dismantlers, shredders, and recyclers) significantly differ from country to country and they are tailored to the national/local operational context. In general, they are based on framework arrangements between the industries combined with specific commercial contracts between dismantlers, shredders, and recyclers for the supply of parts and materials. When cascade recycling or closed material loop do exist, other contractual agreements apply between recyclers and carmakers. In some countries, e.g. in France, different car companies share the same networks of dismantlers, shredders, and recyclers. The reciprocal agreement between BMW, Renault, Fiat, and Rover extend the sharing of dismantling networks at the international level. In those countries having national voluntary agreements in force, the latter operate as the upper-level framework for the specific contractual arrangements at the company level.

From the networks, many significant consequences emerge in terms of knowledge transfer and technical adaptation. Even in the absence of specific and legally binding regulations, dismantlers are usually asked to perform specific operations on ELVs in specific ways that reflects technical, environmental, and economic requirements normally agreed with other industries and reflecting the actual and expected evolution of regulations. These requirements are specified in general terms in national voluntary agreements and are not too different from those included in the EU Directive proposal. Many technical specifications originates from past and on-going experiences inside car companies (dismantling pilot plants), joint research efforts, or co-operative research at the international level. The elaboration of IDIS, the dismantling guidelines by EuCar (see below) suggests that information/knowledge transfer from carmakers to dismantlers is increasing, and technical specifications on dismantling are undergoing a process of standardisation. The common aim is to reduce the cost and increase the quality of dismantling.

On the side of dismantlers, the technical and environmental requirements for participation to networks implies adaptations similar to those to be undertaken when formal regulation of dismantling operations will be in force at the EU level and in Member States (e.g. registration and certification). Although in principle independent dismantlers can reach the same technical level, the participation to networks can offer the advantages of stable demand for dismantled parts and gains in market share. In most industrial networks, shortcomings in both knowledge transfer and technical adaptation by dismantlers do emerge, and the problem of control and continuous selection of the network partners is clearly perceived by industrial actors.
Another on-going organisational change is the increasing attention to spare parts by some carmaker. Various companies are investing in the organisation of collection and reconditioning systems of spare parts from their models arising from repair shops and, sometimes, from dismantlers. The potential for these developments on "reuse" is judged from very good to problematic by different carmakers. The provisions to be introduced in EU Directive on reuse as well as the control of spare parts for reuse can positively influence both an appropriate working of the spare-parts market and the interest of carmakers for it.

III.2.3. Design for dismantling (DFD)

The transfer of information and knowledge inside downstream networks is part of general innovative developments in the field of design for dismantling (DFD). Starting from the very beginning of the ELV problem in late-1980s, most car producers began to study and adopt solutions for favouring efficient dismantling (e.g. to reduce dismantling time and/or to recover more/better and/or to recover at low environmental impact). DFD is a design tool that evolves according to practical experience. In general, it may consist of small changes in the part-assembling systems in order to reduce dismantling time, the latter being a significant variable for the economic balance of dismantling. In other cases, it may imply the change of some components and, thus, adaptations in other components and parts that can spill into more extensive design changes, sometimes even involving materials, e.g. clipping systems without metal screws. The boundaries between DFD and design for recycling as well as car design as a whole, therefore, are not clear-cut and DFD generally involve co-operative interactions inside and outside the car company.

Most car producers introduced —in some cases since many years— dismantling manuals to be supplied to dismantlers. The development of dismantling guidelines and information systems recently gave rise to IDIS (International Dismantling Information System) developed starting from 1992 by carmakers involved in the specific project of EuCar —the R&D branch of ACEA. Presented in October 1999 and distributed to around 2,000 dismantlers in Europe, IDIS contains in particular a set of instructions for fluids’ drainage and the handling of substances requiring special treatment.

The improvement of dismantling has been addressed also through marking systems aimed at identifying the different polymers according to the available ISO and other standards. Because of the number and the complexity of plastic types used in cars, in fact, their identification in post-consumer operations is a significant problem. It is commonly recognised that parts’ marking is still disregarded at the dismantling level (personal communications). Infrared technologies for the identification of different materials are being developed although their diffusion is still limited (see Nijkerk and Dalmijn 1998).
III.2.4. Design for recycling (DFR)

The developments of DFR are guided by still evolving criteria (see Technical Analyses of this Report). DFR requires some kind of definition and measure of "recyclability". The common view by car producers and experts is that, although from the purely technical point of view most parts and materials are recyclable, the problems for recyclability arise on economic and organisational grounds. Various materials from car do not have well-developed secondary markets or can be so difficult to extract from alloys and combinations —the latter being tailored to the components’ functions— that their recycling have to face lacking demand and high costs. The problem, which is at the very core of the ELV issue, is selectively more significant for some materials, and in particular some polymers (see Mayne 1998, Ratcliffe 1994, Van den Berg et al. 1998). As discussed in Par. III.6 below, recyclability is a mixed technical and economic concept (see also Bontoux et al. 1996).

Most European carmakers work since many years to develop "recyclability coefficients" for the different materials and components in the form of parameters to be used in the design process. Recyclability coefficients, which are usually not publicly available (for a partial exception see the BMW case in Part II), include both technical and economic variables. In general, they take into account dismantling costs (which suggests weak boundaries with DFD) and information on recycling operations, but they seems to contain also evaluations on recycling potential together with actual recycling feasibility.

DFR generally produces guidelines for component design and material selection. Recycling departments of various companies produce DFR manuals for internal use that include the options and suggestions about design choices, which are updated according to evolution of variables entering the evaluation on recyclability. DFR involves to a great extent also materials’ and component suppliers. Most car makers have specific lists of substances and materials that are not admitted or undesired, also according to the evolution of regulatory framework on hazardous substances, and use these lists in the technical specifications for component suppliers. The latter are also subject to more general guidelines on how to make components, e.g. painting, which are drawn up according to recyclability/dismantlability objectives. Also DFR guidelines for external suppliers are subject to adaptations based on foreseeable developments of regulation. In this regard, the guidelines and listing systems can represent an instrument for "responsibility transfer" between industries. It must be noted, however, that component producers are not passive actors in car design and their ability to supply solutions to specific recyclability problems can influence the development of DFR itself.

As a part of the general design process, DFR is subject to various constraints emerging from the different functions to be satisfied by car components and materials. It is generally claimed that car is a big compromise between very different and reciprocally constraining requirements. In this framework, costs do matter. In general, then, one can speak of DFR as a complex and evolving set of technical prescriptions to use "recyclable" materials and components whenever possible, given the functions that materials, parts and components have to perform and given the relative costs of different materials/components. Nevertheless, DFR together with DFD and LCA is already giving rise to some practical consequences also in the light of "recyclability" provision of the EU Directive.
Many carmakers are actually trying to increase the amount of recycled materials used or allowed to be used in new car manufacturing. Specific provisions on the possible use of recycled materials in specific parts and components are part of DFR guidelines. These materials, and in particular recycled plastics, sometimes come from the recycling loops starting from ELV in the form of “cascade recycling” (i.e. the use of recycled plastics in increasingly critical components at each subsequent round). Currently, the most developed closed loop for cascade recycling is that of polymeric bumpers (see Part II).

### III.2.5. Life-cycle analysis

DFR is increasingly linked to the development and use of Life-Cycle Analysis (LCA). Most carmakers are investing in LCA analysis at the R&D level and, in many cases, they are already transferring some results in practical choices (see examples in Part II and Technical Analyses of this Report). The current state of LCA is rapidly evolving but it is still weak at both theoretical and applied level. There is a great arbitrariness in the choice of variables and boundaries of the process to be examined, the information requirements are very high, and there are difficulties in finding neutral systems for aggregating and weighting the different variables (see Ayres 1998 and 1999, European Commission 1998b). In the case of automobile, LCA is generally still limited to specific materials or single components as car is considered —although not unanimously—a too complex product to have complete LCAs (personal communications). LCAs applied to car materials and components typically are characterised by great sensitivity to parameters and can gives rise to various trade-offs even at the level of environmental impacts of different material/component. At the decision making level, additional technical and/or economic variables are used to solve trade-offs, including perceptions about the priorities of social actors (consumers, opinion makers) and policy makers. One important aspect of LCAs analyses applied to materials and components is the apparently dominant role of variables representing energy consumption during car useful life that pushes in the direction of systematically preferring energy-saving materials and components. Although there may be mismeasurement of other life-cycle properties, as the environmental impact of landfilled materials at the end of car life, the suggestion from LCAs performed by car companies is to prioritise energy-emission objectives compared to recovery/recycling objectives.

### III.2.6. Material regime simplification

The development of DFR, probably in combination with expectations about ELV regulation, already induced most carmakers to pursue a simplification of the car material regime. The latter tends to favour “easily” (i.e. economically) recyclable materials and seems to imply the weakening of the favourable trends experienced by polymers and composite materials during the surge of the "material revolution". At present, the impact is mainly in the direction of inter-polymer competition and substitution and it seems not to represent a clear reverse trend away from plastics.

There is the propensity to decrease in the number of polymers, and inter-polymer competition seems to favour those plastics with the best recycling possibilities. The share of some polymers
in car material mix is correspondingly increasing. A relative decrease of thermosetting plastics and resins, which have difficulties in recycling, is observed while the thermoplastics' share is relatively increasing. Among thermoplastics, polypropylene is gaining share in European and Japanese car models. Polyurethane is subject to a relative growth but potential obstacles come from low recyclability. Negative trends are instead foreseeable for PVC, which is expected to increasing regulation constrained. Composites materials are not favoured by recyclability requirements while they preserve a very important potential role for energy-saving and emission-saving requirements.

These trends can be viewed in the perspective of future ELV regulation and the design adaptations requested to comply with it. The trend towards increasing intensity of polymers among car materials assumed an extraordinary significance on many grounds, including the environmental one through the contribution to lightness (see Amendola 1990, APME 1996, Cardani and De Liso 1991, Cohendet and Ledoux 1994). Furthermore, there is a still very large potential for innovative polymer-based advanced materials, in particular composites (see APME 1998, EuCar 1994). The material simplification process suggests, therefore, the possibly ambiguous nature of the regulation-induced innovation on environmental grounds (see Policy Recommendations).

At the same time, however, they suggest that DFR can be an opportunity for the car industry to reduce the need for managing a great number of materials and prevent a possible excess variety or over-choice of materials, in particular polymers. Some implications may arise for the relationships between chemical industry and car industry as well as component producers working in between. The great role gained by chemical and component industry in car design can be alternatively reduced or enlarged depending on the ability of the supplier industry to propose solutions to recyclability.

**III.2.7. Material competition**

Competition between metals and related substitution processes can arise from different impulses introduced by ELV policy and related design adaptations.

The position of ferrous metals in car material mix seems to be somewhat reinforced by ELV regulations and DFR adaptations, especially if the latter should involve adverse impacts on polymer-favourable trends. Some problems for steel alloys can derive, instead, from the provisions on “heavy metals” included in the EU Directive. The costs and difficulties of complying with the stringent requirements on lead and chromium, for example, can stimulate substitution process with other metals that are already under research but with some difficulties (personal communications). The substitution process can create mainly redistribution processes between different sectors inside the heterogeneous non-ferrous metals industry.

The search for recyclability can favour light and "recyclable" materials. A case in point is generally considered aluminium (AL) but its favourable trends among car materials (see Part I) have multiple causes and ambiguous implications for car recyclablity objectives.
Among the various favourable properties of AL the most significant is lightness, as suggested by LCA balances—especially in the case of recycled AL intensively used in car making—that make AL an ideal material for energy/emission efficiency goals. Furthermore, significant research efforts are going on to fully exploit the properties of AL as a structural material (see EAA 1996). These attempts arrived at the production of Audi A8 in 1994, which uses AL as the main structural material as well as other experiences, e.g. the Ford-Alcan cooperation for a prototype. Leaving aside the need of redesign imposed by a massive use of AL for structural parts, these trends are still constrained by economic factors, i.e. the relatively high costs of AL compared to other materials, although the very favourable energy balance during car life can compensate consumers for higher car prices.

From the recycling point of view, AL is mainly a substitute for steel and other fully-recycled metals, and this can greatly reduce its contribution to overall recyclability of car. If recycling targets established by regulation (or self-imposed) are defined in percentage of total weight, it must be taken into account that AL is fully recyclable but, at the same time, also reduces the total weight. The paradoxical result might be that a massive substitution of AL for steel can reduce—and not increase—the possibility of target attainment. Even though AL is fully recyclable, the share of non-metallic (possibly non-recyclable) parts in total car weight can be higher in an AL car than in a traditional one. This paradox must be taken into account in possible future technical regulations about recyclability, as those envisaged by the EU Directive, by considering material recyclability and car recyclability as two overlapping but separable issues. AL can also substitute for polymers in some applications and, in this case, it can preserve lightness while contributing to overall recyclability.

### III.2.8. Plastics recycling

The threats of intra-polymer substitution and inter-material competition are giving rise to intensified R&D efforts by plastic producing/recycling industries (see Technical Analyses of this Report). The possibility of increasing plastic recycling from cars has been addressed by a great number of specific research initiatives and major co-operative research efforts by car makers and plastic producers, as in the case of RECAP project, the ELV thematic network co-ordinated by IXAS-Conseil, the PRAVDA 2 project in Germany, the CARE project in the United Kingdom (see Part II, RECAP 1997, IPTS-JRC 1996). Although they are differentiated for the different polymers, the limiting factors emerging from both research and industrial experiences are not purely technical and are, instead, largely of economic nature.

Economic balances of plastic recycling are weak for many polymers due to dismantling and logistic costs. Some polymers are used in pure form in large car components (e.g. bumpers) and are easy to reprocess. Many other polymers, instead, are combined in components in small

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71 Suppose that the initial weight of a car is 1000 kg with 750 kg of steel (75% recyclable) and 250 kg of other materials (25% non-recyclable). Suppose that 650 kg of aluminium can completely substitute for 750 kg steel giving rise to a weight decrease to 900 kg but still including 250 kg of non-recyclable materials. The recyclable share (aluminium) of total weight now amounts to around 72% while the non-recyclable one is around 28%.

72 The analysis is also based on the interviews and personal communications from APME (March 4, 1999), Enichem (January 19, 1999), IXAS-Conseil (April 8, 1999), and recycling departments of carmakers.
quantities and are incompatible for recycling, and then must be separated before reprocessing. Other polymeric materials are composites in which the base polymers are difficult to separate even at the technical level. At the dismantling phase, the separation of polymeric parts (in particular: fuels tanks, dashboards, bumpers, seats, and door panels) is usually expensive also for large and homogenous parts. The costs can be reduced only by a series of improvements in technology, organisation, and DFD. Simplification of the plastic regime in car making can help in reducing such costs, although at the expenses of the market share of some polymers. A critical problem remains transportation cost of plastics scraps that can have a great incidence on total operating costs. The minimum efficient scale of operation of recycling plants for many polymers is relatively high and, given the small total quantities arising from ELV, this implies a large geographical area of procurement, i.e. very high logistics and transportation costs. The critical role of the dismantling phase and logistics as limiting factors clearly emerges from the work by IXAS-Conseil (personal communications).

An additional constraint comes from the still limited applications available for polymers recycled from ELVs. In the industrial experiences, the problem has been faced by developing “cascade recycling” (see Part II) but the potential for cascade recycling and closed material loop is considered to be constrained. According to RECAP project results, although 40% of the plastics in an average ELV can be dismantled by 2000, the technically proven applications of the arising recycled plastics in car making is about 16%. Similar limitations are suggested by APME that estimates the potential rate of plastic recycling from old cars at 10% in 2006 and the possible demand of recycled plastics in car making at 4% of total quantities in the same year (see Mayne 1998). The car-company experiences examined in Part II, however, suggest that the feasibility of introducing recycled plastics in new car models can be greater than expected, and efforts in this direction are increasing.

Mechanical recycling of post-consumer car polymers at the industrial scale is limited to some specific polymers from (and in) some specific car components. The recycling of polypropylene boxes of batteries is well developed mainly because collection costs are joint-costs of the battery (lead) recycling chain; the loop for bumpers is well established in the case of polypropylene bumpers, mainly because of developments of cascade recycling; positive developments are underway for polyethylene fuel tanks. The recovery/recycling of PUR foam is subject to some developments but with various limitations, while limited possibilities still exist for recycling of multi-polymers’ dashboards. In general, a good potential exist for thermoplastics but the low virgin material price has a critical role in pushing production from recycling towards specialised productions that have limited size of final markets (personal communications by IXAS-Conseil).

Feedstock recycling of plastics is an innovation that could overcome most of the problems arising in dismantling and logistics of mixed plastic streams. Feedstock recycling technologies breaks the plastics down into their chemical constituents. The latter can then be used as building blocks of a large variety of new intermediate and consumer products. The process take place at the chemical plants thus starting from scraps that are subject to limited pre-treatment operations, and it is less demanding than mechanical recycling. These technologies are mostly under development. They are currently applied only by two major petrochemical companies – not to automotive plastics (personal communications). There are not industrial experiences underway
for plastics from ELV, but from the experiences in the framework of RECAP project the solution has been proven to be feasible and reasonable (see RECAP 1997).

Various possibilities of innovative uses of recycled mixed automotive plastic outside car production exist and are explored by producers. Together with relative costs and possible competition from recycled plastics streams originated by other sectors, a key limiting factor can be technical specifications and criteria in public procurements (personal communications by APME).

III.2.9. ASR recovery

Plastics can represent up to one third of ASR by weight (see Part I, RECAP 1997) and the possibility of energy and/or material recovery of ASR represents a significant opportunity to avoid the existing constraints on mechanical recycling of plastics. More in general, energy/material recovery of ASR is considered by carmakers and material industries as a valid and/or indispensable way to achieve the targets for non-landfilling of ELV waste. The limits to ASR energy recovery imposed by EU Directive are, therefore, a point of contention.

Energy recovery of ASR (and tyres, see Part I) in waste incineration plants and cement industry attracted innovative efforts and investments. Energy use of ASR has been a part of ELV pilot projects in France, Italy and Germany, and its use in the cement industry has been developed in France. Plastic producers supported these experiences because of the advantages they can get from this solution. The results from both industrial and research experiences, for example the study in the framework of ECRIS (see Stiftelsen Refsorks 1998), suggest that energy recovery can be a rational solution from an economic point of view, given that calorific value of ASR is comparable to that of coal. Positive environmental results come from some LCA analyses of ELV recovery (see ECRIS 1998). Other studies, however, and in particular those made for DG ENV and ARN (see Van der Berg et al. 1998, Roorda et al. 1996), put into question the LCA balances of energy recovery of ASR (and plastics in ASR), and conclude that environmental balances of mechanical recycling are more favourable than those of energy recovery. These differences may confirm that LCA can still be a non-completely reliable policy tool.

Various attempts are underway to separate and recover the materials in ASR (non-ferrous metals and plastics) and to recycle them. Experimental experiences have been made in the framework of ECRIS project, and pilot projects have been started by ARN in the Netherlands and ARGE-Altauco in Germany. Material recovery of ASR can give rise to favourable solutions to the ASR problem by reducing to the minimum the amount to be landfilled.
III.2.10. Metallurgical recycling

A “radical” innovation for dealing with ELV, the “metallurgical recycling”, has been developed by Mercedes Benz in co-operation with Voest-Alpine. It is based on the direct melting of ELV in a melt-reactor were the separation of ferrous metals occur. The organic materials are incinerated to produce heat and to increase the carbon system of the steel fraction. The inorganic material end up as inert slack in which potentially hazardous substances are fixed (IPTS-JRC 1996).

The main feature of this technology is the possibility to make inessential the dismantling and shredding phases. The investments required are relatively high and its technical merits are questioned given the remaining problems about the output quality. It is subject to research and experimental efforts but, at present, its commercial development is at a standstill (personal communications by Daimler-Chrysler).

III.2.11. Co-operative research initiatives

In addition to individual research investments by carmakers, material producers, shredders, as well as other industries, the technical and organisational innovations in ELV management have been the subject of various cooperative research efforts during the 1990s. Table III.1 summarises some selected initiatives undertaken together by different industries in the same country or at the international level.

Although the boundaries cannot be very clear-cut, the co-operative projects can be divided in two main categories: (a) projects addressing ELV management in general; (b) projects addressing specific innovations and technical solutions. The ELV Project Group and PRAVDA 1 in Germany can be considered as examples of the first category because of the large industrial participation and the focus on integrated solutions to ELV – also including policy suggestions. Some of their results have been already described (see Part I and Part II). The other projects mainly belong to the second category. RECAP and PRAVDA 2 have been focused on plastic recycling, and the same largely applies to the DG RTD-sponsored thematic network managed by IXAS-Conseil. CARE (United Kingdom) and ECRIS (Sweden) represent country-level initiatives to address a whole set of innovations for managing ELV, thus having some degrees of generality, but they have strong emphasis on specific technological aspects. The same applies to “Major Innovative Projects” developed in France.
Table III.1
Selected cooperative research efforts on ELV in the 1990s

<table>
<thead>
<tr>
<th>Name/acronym</th>
<th>Participants</th>
<th>Time frame</th>
<th>Focus</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELV Project Group</td>
<td>Around 40 industrial and professional organisations, national policy makers</td>
<td>1990-94</td>
<td>ELV integrated management and policy</td>
<td>--</td>
</tr>
<tr>
<td>EUCAR</td>
<td>ACEA carmakers</td>
<td>1994-...</td>
<td>DFD guidelines (IDIS 1992-99) and DFR guidelines; environmental aspects of materials</td>
<td>*</td>
</tr>
<tr>
<td>RECAP</td>
<td>EniChem, DSM, FIAT, PSA, Reydel</td>
<td>1990-97</td>
<td>Mechanical recycling of plastics</td>
<td>18 MECU</td>
</tr>
<tr>
<td>ECRIS (Sweden)</td>
<td>Volvo, Stena Bilfragrafmentering, Gotthard Nilsson, Jonkopings Bildemontering, and other partners (SBR, BIL, research institutions)</td>
<td>1994-98</td>
<td>Life-cycle analysis, dismantling, material recycling, energy recovery, hazardous waste, economic aspects</td>
<td>na</td>
</tr>
<tr>
<td>Major Innovative Projects (France)</td>
<td>Ministry of Industry, Renault, PSA Peugeot Citroen, and other 21 companies in various sectors</td>
<td>1992-97</td>
<td>Recycling automotive plastics, recycling of SMC/BMC, energy recovery from ASR</td>
<td>around 19 MEuros</td>
</tr>
<tr>
<td>CARE (UK)</td>
<td>Sixteen car companies operating in the UK; technical projects with other industrial partners</td>
<td>1995-...</td>
<td>Dismantling, fluids removal, plastics recycling, energy recovery, parts reuse, economics of recycling</td>
<td>na</td>
</tr>
<tr>
<td>PRAVDA 2 (Germany)</td>
<td>Car industry, material producers, dismantlers, plastics recyclers</td>
<td>1993-1996</td>
<td>Mechanical recycling of plastics from ELVs at the industrial scale</td>
<td>na</td>
</tr>
</tbody>
</table>

* Total resources estimated in Master Plan 1994-98 for research on “Materials and related technologies”, including recycling, are 300 mio/ECU. ** EC contribution.
Source: various documents and personal communications.

As a part of EuCar-ACEA activities on car innovation, the EuCar initiative on recycling has a focus on specific technological aspects. Materials and recycling had a significant but not dominating role in EUCAR Master Plan (see EUCAR 1994). Out of a total amount of 2,430 million/ECUs of research resources requested by the Master Plan, 300 million/ECUs were allocated to R&D on “Materials and related technologies”. The other major area of environmental interest (“Integrated vehicle technologies”), which included energy and emission...
saving with emphasis, received an allocation of 650 million ECUs. In the research area on materials, recyclability/reuse was one among the other strategic objectives and tasks, and included again energy saving as a priority. Furthermore, among the specific research areas, that on light materials, plastics, and composites received a greater attention than recycling. Nevertheless, EUCAR is going on with the elaboration of specific tools of common interest to European carmakers in the field of ELV and car recycling. In addition to IDIS in the area of DFD (see above), the expected result is a common set of guidelines for DFR which is going to be released.

Co-operative research projects on ELV at the industrial level are important on many grounds. They arise from the common perception about the limitations of an individual-company approach. The prevailing multi-industry and multi-competence profile of the projects depends more on the nature of the problem than the need to share huge research investments. Although each carmaker and many material producers undertake individual research efforts, co-operative research opens up the possibility of common knowledge creation and transfer. Further to enabling an easier achievement of practical results, knowledge sharing creates a system of reciprocal externalities that can greatly help the definition of possible innovation directions and their feasibility. In addition, co-operative research efforts contribute to the definition of the common technical knowledge to be used in the policy-making arena (see Par. III.5).

### III.3 Systemic innovation

Most specific innovations have systemic features at the micro-technical level. The specific change they address must be accompanied by other technically-coherent changes aimed at preserving the function of parts and components involved. This is the case, for example, with DFD that, although aimed at making dismantling easier, can require material adaptations, or with DFR and material substitution that, although aimed at increasing recyclability, may require more extensive design adaptations possibly interfering with other functional requirements of components/parts.

The systemic nature of ELV innovation, however, is more general and applies at the macro-level of car making system and the relationships in the chain. Most innovative developments require the simultaneous involvement of different industries operating in ELV and car making by demanding common efforts and close co-operation at the technical level. This is the case of plastic recycling that requires appropriate dismantling and logistics operations to be feasible. Specific innovations occurring in a specific phase (industry) of the ELV chain require, for technical and/or economic feasibility, other innovations in other parts of the chain.

The systemic dimension of ELV-related innovation is made even more significant by the requirements established by ELV policies and regulations. The latter makes ELV-related innovation a process targeted to the achievement of specific objectives on decreasing ASR landfilled —be they voluntary or legally binding in nature. The “measurement” of the different innovations in terms of their contribution to the targets reveals that none of them, if taken alone,
seems to be able to achieve the targets and a set of interdependent innovations in different areas and industries is required to pursue reuse/recycling/recovery targets.

The full perception of this systemic profile can be considered as a parameter of evaluating the potential effectiveness of policies themselves (see also Zoboli 1998).

III.3.1. Inter-industry co-operation

Although the car industry is the main actor and the “natural” coordinator or “responsible” of the ELV innovation process, other industries in the ELV chain have a specific innovative role to play that cannot be assumed by the car industry without forcing the latter to go beyond its industrial operational boundaries. The basic innovative change required by ELV management is, therefore, the creation of new inter-industry links of organisational and technical nature. Inter-industry agreements based on integrated approaches in which specific tasks are assigned to all the industries/actors are the most natural way to pursue solutions. The currently uneven developments and achievements of VAs and industrial networks in the different countries do not reduce the validity of the principle of inter-industry co-operation. Uneven achievements can be explained by specific limiting factors that, for the most part, cannot be removed by alternative non-cooperative approaches. The same applies to the possible distribution problems (i.e. cost allocation) arising inside voluntary agreements (see Par. III.6).

III.3.2. Capabilities’ creation

The innovation process emerging from actual experiences has the features of a knowledge process, characterised by gradual achievements, various degrees of uncertainty and a mechanism of learning from experience. It can be characterised as a capability creation process (see in particular Den Hond 1996). Part of the process is company-specific because it depends on internal ELV-management experience in single car, dismantling, shredding, material producing, and recycling companies. Part of the process, instead, is systemic and based on knowledge externalities arising at different levels inside and outside the industrial networks. The transfer of knowledge on dismantling from carmakers to dismantlers, the role attributed by EU Directive proposal to information from carmakers and component producers to downstream operations, and the cooperative research efforts mentioned above are example of the existence and the need of knowledge externalities. Although for some specific advances, e.g. PVC-free car or innovative technologies for plastic recycling, there could be elements of competition in knowledge achievements, the open and full availability of most knowledge elements is a common interest of all the actors and can be considered as a public good. Industrial agreements in ELV can therefore be considered as examples of capability oriented agreements (see Delmas and Terlaak 1999). The capability creation process is far from being completed. Carmakers and the other industries are still exploring various technical possibilities while pursuing improvements of the initiatives already in place. The still incomplete knowledge of the dynamic outcomes of various innovative options from both the technical and economic point of view induce carmakers to maintaining open as many options as possible, then asking regulators to grant such a flexibility.
The dynamic uncertainty again depends from the systemic dimension of ELV that makes the different innovative options dependent from capabilities of different independent industries.

III.3.3. Company and nation-level specificity

The capability dimension makes the ELV innovation process differentiated at country level. The experiences examined in Part II highlight similarities between the industrial initiatives depending from the similarity of the ELV problem for all carmakers and the knowledge-sharing mechanism. At the same time, however, significant differences do emerge. Some car companies and their networks are more advanced in the creation of material recycling loops, some others in the development of ASR energy recovery, and some others in material substitution. The features of DFR are differentiated between companies. The differences depend on various company-specific factors but also depend on the nation-specific features of the other parts of the ELV chain. The role of shredders in the French system is not found in Italy, for example, and the general weakness of the Italian system for waste incineration make the ASR energy recovery option weaker than in other countries (see Part II). Another example is the central role assumed by dismantlers in some countries, as the Netherlands and Denmark, that do not have a "national" car industry. The inter-industry dimension of ELV innovation process gives a great role to capabilities external to the car companies and the latter, especially in downstream operations (dismantling, shredding, recycling/recovery), are necessarily defined over local (i.e. national and/or regional) economic environments. These features put into question the optimal degree of homogenisation of policy requirements because, for example, “recyclability” can have a different meaning in different national/local contexts and can be a location-specific concept (see Par. III.6.1.3).

III.3.4. Cost-benefit distribution

By involving incremental and uncertain costs that must be distributed among different industrial actors, the ELV innovation process can be critically conditioned by economic variables. Conflicts between different industrial interests and strong competition on various grounds accompany technical cooperation. Economic variables can influence the implementation of technically feasible solutions as well as the choice among them. On the side of recycling/recovery, while the incremental cost of incremental recycling/recovery can be taken for granted, the existence and timing of a corresponding profit is an open issue which largely depends on the ways ELV innovation develops. On the side of DFR, the role of the car industry as a buyer in the materials market is very significant, and a small shift in car material composition can imply a big change in the turnover of supplier industries. Therefore, DFR and related developments pave the way to complex competition processes between supplier industries that can influence the development of different and competing technological innovations. Through both direct regulation and economic instruments, as free take-back, policies can greatly influence the economic relationships in the ELV chain and then, even by this channel, they can influence the innovative options that will prevail (see Par. III.6).
III.3.5. Openness to other environmental problems

The ELV innovation process cannot be considered as closed in itself and is, instead, open to other areas of car making innovation—especially other environmental aspects and performance/safety aspects— as well as waste management technologies depending on the variety of waste streams it produces. The ELV issue is then systemic even in terms of the relevant regulatory and policy frameworks, a point that seems to be disregarded at various levels (see Par. I.4.3).

III.4. Innovation paths

The systemic features of ELV, the current state of many specific innovations, and the targeted nature of technical solutions suggest that ELV innovation is a dynamic process still far from equilibrium (if any) in which different sequences of interrelated specific innovations can be identified and grouped to define different “innovation paths”. The latter can be either alternative or complementary to some extent, given the requirement of target achievement, and the choice about the most appropriate path(s) can be largely influenced by costs and by policies, especially if the latter involve cost re-distribution.

Three general innovation paths can be identified for ELV innovation. They can be defined as: (a) “material-market creation path”; (b) “energy-market creation path”; and (c) “radical substitution path”. They can be sketched in a simplified way to highlight the openness of the process and its sensitivity to policy impulses (Figure III.1).

III.4.1. Material-market creation path

Taking as given the current material composition of an average car, the sustainable achievement of a reduced amount of landfilled ASR is, in general, a problem of market creation for the parts, components and materials currently not recovered, reused and recycled (RRR). The “material-market creation path” is only partially a problem of incremental RRR at the margin for materials that already have a well-developed secondary market (e.g. steel). Take, for example, the creation of markets for recycled plastics. Some innovations are needed for the technical suitability of recycled plastics for existing or new uses, both outside and inside the car industry (i.e. open- and closed-loop markets). This is not enough, however. In order to have the economic suitability of these innovative uses, appropriate (innovative) changes in dismantling activities are needed to have the materials at the appropriate quantities, qualities and costs. The latter achievements can be greatly helped by innovations in car making through the developments in DFD that, as described above, can have flexible boundaries with DFR. This can push in the direction of inter-polymer competition and selective polymer substitution. At the end, not only the process require interdependent changes in different industries but the increasing recycling achieved for some polymers might have detrimental effects on other polymers in car material mix. In general, by preserving the role of polymers as a material group in car making, this path can be non-detrimental for the achievement of environmental goals on
energy-emission to which the lightness of plastics do contribute. Technologies leading to material recovery of ASR can be considered as a significant possibility of material markets’ creation, and require the same type of interrelated changes. Successful material-market creation path can assure relatively high ELV “recyclability” with relatively small and/or well-defined design changes. It is the path requiring the most extensive combination of single innovations among those described in Par. III.2: dismantling networks; DFD/DFR and LCA; material regime simplification; plastics recycling; cooperative research.

**Figure III.1**
Three general innovation paths

### III.4.2. Energy-market creation path

An alternative route of market creation is the development of energy recovery of ASR. It has specific features in terms of the required innovative adaptations. Innovative energy recovery solutions should be developed at the industrial scale because, similarly to material-market creation, markets for automobile shredding fuel (ASF) are still very limited and should be created. This path mainly involves new relationships between shredders and energy consuming industries, or other sectors possibly using waste-derived fuel, that are mostly external to the
ELV system. Therefore, specific economic and technical constraints may arise, e.g. competition with other waste-derived energy sources. The feedback created along the ELV chain would be less complex than in material-markets creation, although some specific requirements for dismantlers do arise in terms of preparation of the material stream becoming ASR. The most important fact is the limited feedback on car material mix and design that can be expected from this innovation path because the energy potential of ASR largely depends on the presence of plastics and rubber residuals. The air emission implications of the energy route to ASR recovery should be obviously weighted against the emissions from conventional energy it can substitute for. At the same times it does not imply trade-off with energy-emission requirements in car making by allowing the current trend towards composites and polymer-based light materials to continue. The pursuit of energy recovery path, however, is policy-constrained from the provisions of the EU Directive proposals but its potential can be significant by corresponding up to half of the incremental car waste non-landfilling required by policy targets.

III.4.3. Radical substitution path

The possible difficulties in pursuing the “material market” and “energy market” paths, which both imply a relatively stable material mix in terms of material groups, can stimulate to pursue more radical adaptations of design and material choice in the upstream part of the ELV system. Let us define this innovation direction as “radical substitution path”. Leaving aside for a moment the possible regulatory constraints on the use of specific materials (e.g. lead) and the associated material substitution impulses, a radical design choice could be to reduce the role of materials currently having weak markets for recycling. The substitution process should not be considered in terms of a radical change of materials' shares (i.e. a reverse trend back to metals). Instead, it should be considered as the reduced propensity to introduce composite and advanced materials not technically and/or economically suitable for recycling. In other words, it can be considered as the interruption of the trend leading to an increasing share of polymer-based materials in car material mix. Further to counterbalance the trend towards increasing average car weights, thus helping the trajectory of low-emission car, polymer-based materials contributed to assembling simplification and have a significant role in the present organisation of the car production chain. The possible multiple trade-off between increased recyclability on the one hand, and simplification of production and lower emission levels on the other hand, suggests that this innovation paths can influence other car innovation trajectories and cannot be considered as desirable by the car industry. The “radical substitution path” can also change the problem of markets creation for recycling: it can reduce the need for developing “new” recycling market (e.g. some plastics) and can create, instead, a problem of marginally increasing quantities in well-established recycling markets (e.g. metals) – a quite different problem from a technological and economic point of view. The “radical substitution path” also tends to reduce the need for innovations in ASR energy recovery.
III.4.4. Preferences, degrees of freedom, and constraints

Different actors reveal to have, both implicitly and explicitly, different preference about the three paths. Policy makers, especially at the EU level, have a strong preference for “material-market creation”, whatever the implications or trade-offs in car design, while they are adverse to “energy-market creation”. Carmakers have a preference for a combination of “energy-market” and “material-market” creation, and try to avoid “radical substitution” and its adverse implications on car making. Dismantlers, shredders, and material producers/recyclers have differentiated preferences for the three paths, and some of them (e.g. shredders and metal producers) might even benefit from “radical substitution”. The latter would be, in general, the most problematic one because it can imply a loss of innovative opportunities, increasing costs, and adverse overall environmental impacts.

Inside each of three paths there are various technical and economic degrees of freedom and constraints. A degree of freedom, for example, is the creativity that the chemical industry often demonstrates in designing and adapting materials; a specific constraint can be the limitations to the potential creation of closed-loop markets for recycled plastics in car making. Different carmakers, industrial networks, and national situations are differently advanced along one or more of the three paths, and have different capabilities to pursue them. Finally, the three paths can be alternative, as sketched above, but can also be complementary through selective combinations, and they can (or must) be pursued together to reach RRR targets, as suggested by the experiences examined in Part II.

It must be stressed that the environmental, technological, and economic results associated to the innovation paths are not completely known in advance. Various specific innovations composing the three paths are not at advanced stages and the three paths are still open to some extent. The uncertainty about results, in facts, becomes evident during the same process of path selection, depending on the specific innovative steps and constraints along one or more paths. For example, the efforts on plastic recycling encountered economic-organisational difficulties and suggested to go on with the organisation of dismantling networks (material market creation path), and/or to develop energy recovery of ASR (energy market creation path), and/or to slowdown composite-materials introduction (possibly radical substitution path). The features of a knowledge and capabilities’ creation process clearly emerge.

If the three paths can be taken as a stylised representation of the currently open state of the ELV innovation process, they can be a useful basic reference to discuss the role that regulation can have in influencing paths' formation and selection through objectives, instruments and specific policy provisions.
III.5. Regulation and the innovation process

Regulation-innovation relationships in the ELV area developed in a very long time-frame — around ten years— and different phases can be distinguished in which the interactions worked (and will work) in a different ways. The most important points emerging during the three phases are: (a) the evolving policy preferences of EU regulators; (b) the role of policy threats and expectations; (c) the process of targets definition; (d) the role of knowledge and principles in policy making.

III.5.1. Interactions in three phases

Three phases in the regulation-innovation relations can be distinguished.

The first phase is approximately from the inclusion of ELV among Priority Waste Streams by the Commission (1989) to the conclusions of the ELV Project Group work (1994). It can be considered as a cooperative phase, dominated by problem identification and options definition. During this phase, some innovative responses emerged, at least as a start-up, as in the cases of R&D investments and plastic recycling, the car industry pilot experiences on dismantling, the first cooperation schemes between car industry and dismantlers, the early definitions of DFD/DFR in car companies. Major cooperative research efforts were established during this phase. Early practical experiences were company-specific and did not bring to significant actual achievements in terms of RRR targets. However, the early results of innovative experiences created the reference for the technical contents of a regulation, and in particular the possibility of defining common RRR targets. In this phase, many country-level policy schemes were designed (e.g. Germany, the Netherlands, the United Kingdom, Austria, Sweden) or initiated (e.g. France, Italy). In Germany and Sweden, the domestic debate on ELV already revealed the deep divergence between policy makers and the car industry that would have to prevail later at the EU level.

The second phase is from the drafting of the EU Directive proposal (circa 1995) to the Common Position of July 1999. This phase was marked by non-cooperative relations between European environmental policy makers and the main industrial actors involved in ELV. The Commission proposed a directive not tailored on the positions of industry, although supported by dismantlers, and different from the suggestions of ELV Project Group in many respects. Carmakers and other industries pursued innovative advances along the innovation lines defined in the "first phase". In particular, car producers went on with the organisational links with dismantlers and shredders, as well as plastic producers. Actual results were achieved in terms of RRR rates by some industrial networks and national agreements. The plastic industry intensified the research on technological options for polymers in car making while carmakers made additional steps on DFD/DFR. In the meantime, a significant lobbying activity by the different stakeholders took place, also based on accumulated knowledge and experience in ELV management. During this phase, various national VAs or policy schemes, also backed by legislation, entered into force (the Netherlands, Austria, the United Kingdom, Germany, Sweden) or were designed with an
acceleration during the debate on EU Directive proposal (1999). In particular, after the initial strong controversies, the German and Swedish policy schemes emerged as compromises between the positions of industry and those of regulators. The implementation of the Dutch policy scheme created a new approach, largely alternative to those under implementation in other countries, that was much criticised and opposed by carmakers (see Par. III.6).

The third phase starts from the 1999 Common Position and will go on, after the adoption of the Directive expected in 2000, through the transposition in the national legislation and the control/revision procedures. If not substantially modified during the next steps of the adoption procedure, the 1999 Common Position opens up new possibilities compared to the 1997 Directive proposal. In particular, the possibility to comply with the most important provisions by voluntary agreements gives a greater role to country-level policy making, although the existence of a common legally binding provisions will bound the relationships between national policy makers and industry. The variety of national approaches might be reduced starting from the present situation in which national/industrial VAs have different features at different stages of development, including different instruments at work. The ambiguity of the 1999 Common Position on the application of FTB, instead, will leave rooms for differentiated national solutions. The Directive transposition process can be expected to influence, although in hardy foreseeable ways, the innovation paths emerging at company and country-level. On the other hand, with the provisions on recyclability/recoverability/reusability the focus of the regulation-innovation mechanism is likely to shift towards the relationships between industry and standardisation bodies for amending type-approval regulations.

III.5.2. Policy threats and regulation expectations

In general, policy threats and expectations about regulation strongly shape the whole innovation process in ELV and assume a great role for the definition of industrial strategies.

In the three-phases scheme, the most visible fact is that specific as well as systemic innovation achievements occurred—or began to take place—as early as the first phase, and many of them developed during the second phase, before the most important regulation impulse at EU level was completed and introduced in the system. The same applies also to country-level regulation and policies, for example in Germany, Sweden, France, and Italy. The policy formation process itself had the nature of a complex impulse to innovation through policy threats and expectations about regulation. This conclusion applies also to expectations about specific regulatory provisions that influenced the direction of innovative efforts. For example, the ongoing simplification of plastic-material regime was influenced by expectations on recyclability provisions together with expected constraints on ASR energy recovery included in the Directive proposals.

The implementations of national VAs and industrial networks has been the way in which industry tried to prevent a policy impulse in the form of detailed regulation, as the EU Directive,

73 On the role of policy threats in environmental policy see also Segerson and Miceli (1997).
and/or to influence its features through the demonstration effect of VAs achievements. At the same time, the same initiatives satisfied the need to be prepared to operate in a regulated environment and, for individual carmakers, to avoid the position of the laggard in ELV management and DFD/DFR.

The change in regulation expectations that occurred with the transition across the three phases also influenced the reactions by industry and reinforced some directions of change. The shift to the second phase, for example, reinforced the propensity of carmakers to create relationships with the downstream operations, and dismantlers/shredders in particular. It also accelerated the establishment of national agreements during 1998-99 when EU Directive proposal was high in the policy debate. The same impulses also apply to instruments. The establishment of the German and Swedish agreements in 1998, both including a form of producers responsibility and “controlled FTB”, seems to be also an attempt to prevent the possible introduction of a “free” FTB as that included in the 1997 Directive proposal. At the same time, in some countries, as Belgium and Denmark, the regulations under discussion or recently introduced are closely shaped by the Directive proposal in the attempt to minimise the adjustments to be made when EU regulation will be in force. As a consequence, while VAs were born from regulation threats and tried to influence regulation making and its provisions, the change of regulation expectations during the three phases influenced the pace of VAs establishment as well as their content.

III.5.3. The targets game

The establishment of the recovery/reuse/recycling (RRR) targets has been an important aspect of the expectation game. In general, we can consider targets for RRR as “focusing devices” (see Rosenberg 1994) that define a conventional benchmark for evaluating innovation as a problem-solving process, thus defining also the required innovation effort. The definition of targets represents a critical point for all environmental policies but in particular in the ELV area, where small differences in the percent target-rates for RRR can have big practical differences on what must be done. (Additional five percent mechanical recycling can be a small change for homogeneous packaging waste starting from low recycling rates but it is a critical change for ELV).

If we consider the targets in terms of non-landfilling rates, there is a significant similarity between RRR rates established by the EU Directive and those adopted in national VAs and industrial networks, although some national exceptions do emerge (see Part I). The most fundamental difference emerging from EU targets and country-level VAs targets is that, in most of the latter, the target-rates for mechanical recycling are not established thus allowing free rates for energy recovery of ASR. This has been a critical point of divergence between regulators and industry.

The relative homogeneity of non-landfilling targets across national and EU policies partly depends on technical factors, i.e. similar current rates of recovery/recycling and material composition of ELVs in different countries, but also depends on the process of policy formation during the 1990s. In general, the target-rates originate from industry discussions inside the ELV
Project Group during the “first phase” when little experience and few actual results on ELV management were available. The targets seem to have emerged as rates reflecting a technical potential to be pursued by voluntary commitments and industrial networks as non-legally binding objectives with a free choice of technologies, in particular ASR energy recovery. Further to technical factors, the targets reflected, therefore, technological expectations, policy views, and strategic propositions. In particular, the definition of relatively ambitious targets by industries suggests technological self-confidence, the preference for sharing responsibility, and the political message that a specific regulation was not needed.

Regulators as well as industry did not elaborate about the social optimality of these target rates and, given the relative lack of cost-benefit analysis, the RRR targets in the Directive proposals, as well as those adopted in VAs, cannot be considered to represent “optimal recycling” levels (see Par. III.7). Regulators assumed that, by emerging from industrial discussions, targets were feasible and not disruptive of car industry and other sectors involved and proposed the targets as legally binding while introducing quantified targets for mechanical recycling rates and limits to ASR incineration based on general waste policy preference. Furthermore, regulators took the asymmetric distance of VAs in place in mid-1990s from their own targets as a demonstration of VAs ineffectiveness and went in the direction of uniform legislation across countries as the best policy approach based on the argument of harmonisation (see European Commission 1997).

At present, the most important open issue on the EU Directive targets remains target-timing, and in particular targets applied to cars already in the market at the time of regulation introduction, i.e. the so-called “retroactivity”. By assuming an ELVs age of 10 to 15 years, cars becoming ELVs in 2005 were built in 1990-1995, i.e. during the “first phase” of ELV policy development. Although some of the possible provisions of future regulation might have been guessed by industry in that phase, the 1997 Directive proposal was not in place and its exact requirements in terms of targets’ specification were neither knew nor reflected in car-making choices. Although with less clarity, the same applies to cars produced from 1995 to 2000 that will become ELVs in 2005-2015.

**III.5.4. Policy principles and technological knowledge**

The relationships between EU regulators and industries in the “second phase” have been shaped by different positions on responsibilities’ distribution and costs’ allocation that reveal different reference principles and different views on the role of technological knowledge in regulation.

Concerns about technical feasibility and costs shaped the industry positions. The systemic features of ELV innovation illustrated above as well as the emergence of significant “incremental costs” for targets attainment led industry to policy principles as shared responsibility (i.e. inter-industry cooperation and cost sharing), free market mechanism (e.g. recycling loops self-sustained or not structurally supported by incentives), flexibility of technical solutions and their combinations (e.g. both recycling and energy recovery acceptable according to the specific situation). The technical complexity of the issue also allowed industry to use
technological knowledge in a strategic way in the policy debate, e.g. emphasis on some aspects and controlled information disclosure.

The position of regulators in the “second phase” was, instead, dominated by general principles now well established in European environmental policy. It is generally recognised that the Directive proposal 1997 was in the line of the EU packaging directive (1994) and rooted in the same principles. The latter can be considered the producer responsibility principle (PRP) or the extended producer responsibility principle (EPRP), both representing a legal-level evolution of the Polluter-Pays-Principle (PPP) - basically an economic principle. From the legal point of view, the 1997 Directive proposal is then strongly backed by previous and incoming legislation on waste while exploiting the flexibility offered by the Treaties in the environmental area (see Onida 1999).

The Directive proposal 1997 focuses on product making to a large extent while maintaining a waste-management perspective. Because of the complexity of car as a product and car making as a process, the involvement of product making greatly enlarged the technological and economic implications of the 1997 proposal, also compared to other waste management regulations. The main technological knowledge about the problem was that produced by industry but EU regulators clearly considered this knowledge as non-free from self-interest and strategic in nature, while the independent research effort developed by regulators in the specific area of ELV was limited. In these conditions, the priority assigned to EPRP by regulators could have been a way for facing asymmetric information by giving industry the role of the “best solver” (see Natale 1994) that have full social responsibility also in terms of costs. However, the best solver principle, as well as the EPRP, does not necessarily bring to specific policy instruments while EU regulators made specific choices on the latter. In particular, the 1997 Directive proposal departed form a VAs-based approach in favour of the direct introduction of specific economic instruments which superiority in terms of dynamic incentive effects (i.e. innovation in recycling and recyclability) remains to be demonstrated (see Policy Recommendations).

The innovative element of addressing product-making in a waste policy, as pursued by the 1997 Directive proposal, failed to bring to innovative policy approaches in the direction of Integrated Product Policy. Regulation choices went along traditional waste-policy lines while industry went along traditional defensive attitudes towards EU environmental policy based on excessive-cost arguments. A key factor has been the difficulty of finding common grounds about technological information/knowledge and its use in regulation. This failure suggests the need to explore innovative tools, as "best practice" analysis, in order to exploit all the technological (and then environmental) knowledge available in regulation making (see Policy Recommendations).

III.6. The role of policy instruments as a "selection device"

As in other environmental problems, there are methodological limitations to the impact analysis of single policy instruments on ELV innovation. The EU Directive and national-level legislation – with or without voluntary agreements – are complex policy packages that include a combination of heterogeneous instruments and it is very difficult to define the “partial” impact of specific
instruments because of their extensive cross-influences\textsuperscript{74}. The number of externalities, industrial phases, and actors involved can limit the possibility of considering single instruments as actually separable devices.

The most appropriate approach to policy evaluation would be to consider different policy packages (including VAs) already implemented and to evaluate their ex post performance\textsuperscript{75}. The possibility of applying such an approach to ELV is still limited. Although almost all EU countries introduced ELV policy schemes (see Part I), the history of many schemes is too short and a systematic recording of their achievements is still lacking. Various national schemes are voluntary agreements based only on contractual agreements without direct regulation and/or economic instruments at work. The most articulated policy schemes, as the German and the Swedish ones, entered into force from a too short time to allow evaluation. Some evaluations about effectiveness of VAs will be presented in Par. III.6.3, but they cannot be conclusive neither about policy packages nor about instruments included in them.

These limitations notwithstanding, an attempt can be made to explore the ex ante incentive properties of specific instruments on the innovation process. The expected impact of two kinds of instruments will be considered. Firstly, the possible influence of direct-regulation instruments on the choice among the innovation paths will be addressed. Secondly, the cost-benefit allocation induced by economic instruments will be considered as able to influence industrial reactions and the innovation focus. The analysis is based on country-level experiences examined in Part II, the views expressed by industrial and policy-makers during direct interviews, and economic analysis. Ex post empirical validation is not possible at present, also because some significant instruments (as FTB) are not still introduced.

III.6.1. Direct-regulation instruments and innovation paths

The instruments of direct regulation included in EU Directive and national policies can obviously have impacts on innovation by imposing specific technical constraints on ELV treatment and/or car making that stimulate adaptive investments. To exemplify how these effects can work, we shall consider three instruments: (a) direct regulation of dismantling activities; (b) limitations on ASR energy recovery; (c) provisions on “reyclability” standards. The latter will be discussed in great details because of its importance for the post-Directive developments.

\textsuperscript{74} Even at the theoretical level, although it may exist an “optimal instrument” if considered alone in a non-systemic setting, it can be sub-optimal when integrated in a whole-policy perspective (see Kolstad, Ullen and Johnson, 1990). The role of instruments in environmental policy is examined, among others, by Hemmelksamp (1997), Blazejczak et al. (1999) while the role of instruments in integrated waste policies is examined, among others, by Zoboli (1994).

\textsuperscript{75} The methodological and empirical problems of ex post efficiency/effectiveness evaluation of environmental policies are discussed, among others, by Hahn and Stavins (1991).
III.6.1.1. Direct regulation of dismantling

Provisions on collection/dismantling activities introduced in EU Directive and national legislation are commonly agreed as a basic step for reducing ELV environmental impacts both directly, i.e. less pollution during operations, and indirectly, i.e. less materials becoming ASR as a consequence of the obligation to dismantle parts/components. Because of the incremental costs that these provisions imply for dismantlers, the possible incentive effect of the instrument taken in isolation is mainly a restructuring of industry to face increasing operating costs. A decreasing number of companies with an increasing industrial concentration can be expected – although within the boundaries of local-level operations – together with increasing efficiency at company-level (e.g. computerisation, certification, etc.). However, the possible impact of technical regulation on industry structure and organisational innovation is not sufficient to ensure that a “material market” path will arise. Other innovations along the “material-market creation” path are needed, and dismantling regulation is an incomplete instrument for sustainable innovative solutions. Complementary instruments are needed in order to avoid that more dismantling is not followed by more (domestic) recycling/reuse —undesired results of this kind emerged in some European countries from waste management policies focused on collection, selection and sorting. The preference of EU policy and some countries for FTB or recycling fees as complementary instruments — in contrast with the industry preference for inter-industry voluntary agreements — place innovative outcomes of dismantling regulation in a more general framework (see Parr. III.6.2 and III.6.3). In essence, although it has specific incentive properties towards a specific innovative trajectory, direct regulation of dismantling cannot reach these effects outside an integrated policy package.

III.6.1.2. Constraints on ASR energy recovery

Although the specification of target-rates for mechanical recycling in EU Directive can be considered as a part of the policy objectives, the implied limitation on the rates of ASR energy recovery is a constraint on technological solutions to reach recovery rates, and has a role similar to that of an instrument. It represents, in fact, a policy preference about “best” technologies to achieve policy objectives on non-landfilling of ASR. In terms of innovation paths, the limitations on ASR energy recovery tend to discourage or limit the innovative efforts for “energy market creation” while gives impulse to innovation investments on “material market creation”, in particular on polymeric material recycling. This policy preference can be expected to stimulate the feedback along the ELV chain that, as described above, involve carmakers, dismantlers and material producers. This possible impact clearly brings in the direction of inter-industry relationships and agreements, as those promoted by the car industry but not supported by the 1997 EU Directive proposal. Leaving aside this possible contradiction – partly solved by the Common Position 1999 – this policy choice is selectively more favourable to some sectors, companies and countries, i.e. those with more developed capabilities in mechanical recycling, while it is less favourable for national/local environments where waste energy recovery is a well developed business. Furthermore, by pushing in the direction of other innovation paths, this policy choice might be selectively favourable to some polymers easier to recycle as well as other materials (if the latter are metals, then shredders would be compensated for the lost opportunity
III.6.1.3. Recycling and recyclability

The provision on future regulatory standards of car recyclability, reusability, and recoverability (RRR-ability) is the strongest form of product-making involvement and IPP orientation of the EU Directive. It can be very significant in the innovation-regulation perspective but it opens up the uncertainties on ex ante definition of RRR-ability for a complex product in a technical standardisation framework. Industries are searching for innovative concepts, criteria, and solutions to increase RRR-ability (see Part II and Par III.2) but operators in the ELV chain are still divided about the possibility of reliably defining RRR-ability through standards.

A first level of uncertainty is about the definition of material recyclability. Recyclability of a material does not have standard and commonly accepted definitions. At the technical level, it could be defined as the ability to turn the material in its original state – as derived from natural resources – or in the elementary components of the virgin material, or in other materials that can be substitute for the virgin material – or that can be used in some form. Such a definition is apparently based to intrinsic properties of a material but, instead, it implicitly make recyclability to depend on a specific state of technologies for both material production and recycling. For example, the non-existence of a technology able to turn a used material in its original state may not depend on the properties of the material but on economic conditions that prevented from the invention of appropriate technologies. Even at the technical level, therefore, the definition of recyclability involves the conditions at which a material can be actually recycled. These conditions are both technical and economic in nature and the two aspects can be very difficult to separate. Even in the case that purely technical definitions of recyclability are searched for, the existence of applications and, in particular, economically viable applications for recycled materials can justify the existence and/or the development of recycling technologies and can be, in fact, a requirement for material recyclability.

The significance of organisational and economic variables as constraints to actual developments of material recycling even if materials are technically recyclable (see Part II) is common to various recycling industries (see also Bontoux et al 1996). On the other hand, economic conditions can create a potential for recycling, e.g. favourable virgin material prices, which might not materialise if technical recyclability is lacking. Policies can have a similar role in creating a potential for recycling that might not be exploited if technical and/or economic conditions are lacking, as in the case of technologies for ASR material recovery or "metallurgical recycling"

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76 “In order to prepare an amendment to Directive 70/156/EEC, the Commission shall promote the preparation of European standards relating to the dismantlability, recoverability and recyclability of vehicles. Once the standards are agreed, but in any case no later than by the end of 2001, the European Parliament and the Council, on the basis of a proposal from the Commission, shall amend Directive 70/156/EEC so that vehicles type-approved in accordance with that Directive and put on the market after three years after the amendment of the Directive 70/156/EEC are re-usable and/or recyclable to a minimum of 85% by weight per vehicle and are re-usable and/or recoverable to a minimum of 95% by weight per vehicle” (Council of the European Union 1999, Art. 7.4).
already justified by policy demand but still at early development stages. Legislation and technical standards can positively or negatively influence recycling and then recyclability if, for example, they fail to define the conditions for acceptability of recycled materials in public procurement. Definitions of recyclability might be conditioned by technical standards and legislation in other fields.

Technological and organisational innovations can change the conditions at which technical and economic recyclability can match, and the concept of material recyclability is dynamic in nature. The development of innovations in cascade recycling (see Part II), for example, can increase actual recycling and, at the same time, techno-economic recyclability of materials involved by creating new applications. Innovations in material recovery from ASR or feedstock recycling for plastics can substantially change the technical and economic viability of car material recycling. The development of dismantling/recycling networks pursued by ELV national policies and industrial initiatives can have the same effect of increasing both recycling and recyclability by removing the economic and organisational constraints on the exploitation of recycling technical potential.

Standards on recyclability of materials risk to be loose or to create distortions if they are not able to take into account the mixed technical, economic, and institutional nature of the concept and, in particular, its dynamic features. On the one hand, if recyclability standards are based on purely technical criteria, there is the risk to define as recyclable a material that will never be actually recycled because of economic reasons, or to define as non-recyclable a material that, despite its weak technical recyclability, will be actually recycled because of economic changes that justify recycling, e.g. substantial oil price increases. On the other hand, if recyclability is defined according to current technologies and economic conditions, the risk is that of defining as non-recyclable a material that will soon become recyclable due to innovations or changing economic conditions. Exogenous variables can greatly influence the latter, as in the case of energy prices and primary material prices. An implication of these uncertainties is the difficulty of defining materials as recyclable and non-recyclable as such, and the need to define material recyclability as a rate which can vary according to changing technological and economic conditions.

Even in the case that material recyclability can be reliably defined and measured, the definition of product recyclability (i.e. RRR-ability of new car models), which is the relevant one in the framework ELV Directive, creates specific uncertainties for its impulses on innovation.

The definition of recyclability targets as a rate of car weight (85% in the Directive) make car recyclability a different, albeit non-separable, issue from the recyclability of the materials it contains. The example of aluminium (see Par. III.2) suggests that a car containing large quantities of a 100% recyclable material might be less recyclable in percent of total weight because a changing total weight can be associated to a changing material mix. Car recyclability defined as a share of car weight can largely depend on material mix rather than on the prevailing or average recyclability (measured in whatever way) of the materials it contains. The most important implication is that the same rate of car recyclability can be obtained with different material mixes. For example, the use of many highly-recyclable materials cannot assure high car recyclability if few low-recyclability materials are significant in total weight. In the same way, a significant share of total weight covered by few highly-recyclable materials can assure high car
recyclability even in presence of many non-recyclable materials. The consequence is that requirements on car recyclability create constraints on material choice but, at the same time, they leave many degrees of freedom because the same rate of car recyclability (85% of total weight) can be obtained with different design and car conceptions.

The process of recyclability standards’ definition by the Commission, standardisation bodies, and industry will have to face difficult choices to reduce the risk of adverse innovation impulses. If the recyclability rate of car weight is the main criterion, it is unlikely that recyclability standards can define in details the ways (e.g. material combinations) the rates can be attained. Otherwise, standardisation process would require a full technical and economic knowledge about the different implications of material choice, and the risk of negative influences on other car making aspects might be very high. It is therefore reasonable that the standardisation process will allow different ways (e.g. material combinations) of attaining recyclability rates but this freedom can leave rooms to other sources of uncertainties. For example, if the current state of recycling technologies and markets is taken as a reference for material recyclability, a high rate of car recyclability can be more easily attained by an old-conception car with a large share of “traditional” recyclable materials. In terms of the innovation paths we have depicted, the possibility that a “radical substitution path” is chosen as a way to rapidly attain high car recyclability cannot be ruled out. Obviously, this backward direction of adaptation is bounded by the current state of car and material technology, and it is reasonable that carmakers and material industries will prefer to pursue DFR and innovative recycling technologies.

The way in which standardisation bodies will take into account potential or future innovation in material recyclability, as possibly different from the current state of material recyclability, remains an open issue. This is an important point for a durable product as car. If current state of technologies is taken as a reference, type-approval might be problematic for cars that might be fully recyclable after ten years as a consequence of innovation, but the way innovations of the next ten years can be taken into account is an open issue. In practice, the question is how to take into account on-going progresses in DFR and other R&D efforts that are not still fully operational but might be well developed in the near future. Part of these problems can be addressed by using tools as "best practice“ analysis or technological forecasting.

The Directive provisions address recyclability, recoverability, and reusability together as possible substitutes the one with the other in terms of policy targets.

In the framework of the Directive, recoverability can be mainly referred to the possibility of recover energy from ASR. Recoverability standards can thus depend on the technical availability of energy recovery options and their economic feasibility – a problem not too different from that of recyclability. The constraint on recyclability rate at 85%, however, can make recoverability definition a residual problem consisting on the identification of possible forms of (energy) recovery for 10% of the weight of a new car model.

In the Directive, reusability is mainly referred to parts and components77 and standards could be based on the existence of car models in which parts/components can be re-used. Until a model is produced and/or there are other models in which its parts and components can be reused, also

77 See Art. 2 of the Common Position (Council of the European Union 1999).
taking into account safety considerations, it might be possible to define reusability on ex ante technical grounds. The actual extent of reuse, obviously, can be largely unpredictable because it depends on techno-economic factors such as the speed of models’ turnover and their changing technical features, and the market for second-hand cars and spare-parts. The interesting fact is that, by being reusability a substitute for both recyclability and recoverability in the Directive formulation, the definition of a new car model as "reusable" at 85% or 95% could be enough for type-approval. If reusability is simply defined as the existence of car models in which parts and components can be reused, the attainment of reusability might be easier than both recyclability and recoverability, and it can represent a way-out from many problems of standards’ definition. There can be constraints on such an extensive interpretation of reusability because some components can be known in advance to be non-reusable after the first use. However, treatment and reconditioning techniques might allow extensive ex ante definition of reusability to prevail.

### III.6.2. Economic instruments

The partial influence of economic instruments on the direction of innovation may depend on their cost/benefit implications for different actors and, then, on the (expected) reactions of the latter. Although the evidence from the application of economic instruments to ELV do not allow a true empirical validation, the implications of economic instruments can be discussed on the basis of economic principles and the evidence presented in Part I and Part II.

#### III.6.2.1. FTB, recycling subsidies, and deposit-refund systems: similarities

The main ELV-related externalities are: (a) the dumping of ELVs in the environment; (b) the release of pollutants in treatment operations, and (c) the landfilling of ASR. They can be reduced by addressing different phases and actors of the chain: (i) by providing disincentives to the dumping of ELVs in the environment (consumer level); (ii) by increasing the rate of recovery/reuse/recycling (various industrial levels); (iii) by increasing the dismantling rate and improving dismantling techniques (dismantlers/recyclers level); (iv) by increasing the recovery of ASR (shredders’ level); (v) by increasing “recyclability” of cars (car-industry level).

The instruments introduced (or proposed) in ELV policies to address the above externalities are free take back (FTB), recycling fees (subsidies), and deposit-refund systems. These instruments are often considered as being substitutes the one with the other in addressing the same externalities. FTB, recycling fees (subsidies), and deposit-refund systems can be all aimed at providing incentives: (a) to eliminate the dumping of ELVs into the environment; (b) to

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78 Other economic instruments that might be adopted in ELV policy are specific landfill taxes and subsidies on virgin materials. The reasons for the limited consideration of these instruments in ELV policy are discussed in Mazzanti and Zoboli (1999).

79 In a theoretical framework, neutrality of the chosen instrument with respect to outcome exists under some assumptions, and this open the way to some degree of substitutability between instruments because they should create the same set of incentives by targeting different sets of actors.
increase the rate of recovery/reuse/recycling of ELVs; (c) to increase the recyclability of cars. They address the actors in the “consumer-dismantler/recycler-carmaker” subset and share various features.

By addressing the problem of ELVs having negative value to the last owner (i.e. excessive net costs of additional car dismantling/recovery/recycling), FTB has the refund element of a deposit-refund system. At the same time, as dismantlers transfer to carmakers (through consumer reimbursement) the incremental costs they incur in additional dismantling, a recovery/recycling subsidy element is included in the FTB as formulated in 1997 EU Directive proposal. Finally, carmakers should be stimulated to make more recyclable cars to reduce FTB costs.

An explicit form of recycling credit/subsidy is included in the Dutch scheme that introduces financial transfers to dismantlers and recyclers associated to ARN. The source of financing, i.e. the recycling fee, is a lump-sum recycling tax but, given its constrained destination, it can be considered as a deposit charged on the price of new cars. The Dutch scheme then includes one element of a deposit-refund scheme and, by freeing the final owner from the possible negative price of ELV, it includes a form of FTB. The Dutch scheme can represent a “deposit-recycling subsidy with free take-back”.

Although a deposit-refund system primarily addresses the dumping of old vehicles into the environment by granting the last owner a premium (refund) for delivering the ELV, it can include other incentive effects depending on its formulation. In the early Swedish scheme, for example, the scrapping fee on the first owner was used to finance premiums to both last car owners and dismantlers, thus including one element of recycling subsidy. Deposit-refund systems can be similar to both FTB and recycling fee mechanisms when: (i) a fee is paid by first buyer (deposit) at a level sufficient to free the future last-owner from possible costs for its ELV, and (ii) the reimbursement (refund) is explicitly given, at least in part, to the dismantler/recycler (or the final owner use the refund received to pay for the negative value of old car delivered). Each of the three instruments actually contains, in both theory and practical formulations, some element of the other(s).

A deeper examination of the instruments, however, reveals that they can have quite different incentive structures even at the theoretical level. The features of the instrument and the stage (industry, actor) at which it is applied can be significant for its impact on cost-benefit distribution between actors, and then for innovative responses (effectiveness). In particular, similar instruments applied to different levels of the ELV chain can lead to different reactions in terms of innovation/adaptation paths pursued by the actors. A comparison between FTB and recycling fee can highlight these differences.\(^{80}\)

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\(^{80}\) Analytical arguments in favour of different features of the two instruments are examined by Palmer and Walls (1999).
III.6.2.2. FTB and recycling fees: different cost-benefit implications and innovation incentives

The static allocation properties of FTB and recycling fees, i.e. the two most debated economic instruments in ELV policies, are compared in a very simplified way in the Appendix. Even at the conceptual level, significant differences do emerge in terms of the incentives they possibly introduce into the system.

FTB is based on the idea that dismantling/recycling industries are a weak ring in the ELV chain. The cost of incremental dismantling/recycling imposed by policy, therefore, should not be supported by them (in particular by dismantlers), because of high costs of dismantling/recycling are a consequence of car-making choices (design and material mix). The final targeted actors are carmakers and recycling industries but the incentive is placed on the transactions between last-owners and dismantlers with the expectation that it will be transmitted to both upstream and downstream actors. FTB is then an incentive instrument based on expected economic reactions.

The FTB mechanism of EU Directive proposal 1997 is a “free” FTB mechanism in which dismantlers can freely establish the (negative) price for ELVs (i.e. FTB level), and last-owner will be fully reimbursed by the carmaker whatever the negative price of his/her ELV. In this way, not only all the incremental cost of incremental dismantling should be paid by carmakers but, given that nobody can limit the (negative) price (i.e. payment) asked to ELV-owners, there is also the possibility of a transfer to dismantlers in excess of incremental dismantling costs. The possibility that a great number of non-professional dismantlers try to enjoy free lunches from this mechanism is suggested by the current structure of the dismantling industry in Europe (see Part I). Furthermore, last-owners (i.e. consumers) may have an opportunity cost from a free-FTB system as far as the starting situation before FTB is one in which average positive ELV prices do prevail (see the Appendix).

The possibility that innovations along the "material-market creation path" are stimulated by free-FTB cannot be ruled out, but the narrowly-focused cost-allocation creates various uncertainties about the most likely innovation outcome. Different reactions by other actors are possible.

In the case that FTB reduces the costs and increases the economic quality of materials coming from incremental dismantling, then innovation can go along the “material market creation path”. The new recycling markets are incentive-based, however. Self-sustained markets require in any case innovations in material/parts recyclability/reusability. If innovations on recyclability do occur, then the value of FTB can be gradually absorbed: carmakers can make selected adaptations in design/material mix while paying decreasing amounts of FTB due to increasing recyclability. The need for co-operation inside the ELV chain is very clear for this outcome to prevail.

A less optimistic possibility is that innovations in recyclability are not enough to create self-sustained markets. In this case, FTB-based incentives may become permanent subsidies to dismantling/recycling. Carmakers can make different choices according to the levels of FTB they have to pay and their technological capabilities. The first possible choice is to preserve material mix and related advantages while accepting high FTB costs. In this case, FTB is likely to be passed to consumers in new car prices. Innovation incentive could be greatly reduced and
the main result could be the creation of new recycling markets steadily subsidised by consumers. The second possible choice by carmakers is to increase their economic involvement in downstream operations to "control" FTB. In this case, the “power” of car industry on dismantling/recycling can become greater with FTB than with VAs. The third choice by carmakers could be to make radical design/material adaptations in favour of easy-recyclable (traditional) materials (i.e. to stop trajectories for the substitution of new and composite materials) thus reducing FTB costs. In this case, innovation will go along the “radical substitution path”, and the problem will become incremental recycling in well-established markets.

In essence, FTB can have different innovation outcomes: (a) innovations in recyclability and new self-sustained recycling markets; (b) little innovation impacts on car design together with new recycling markets subsidised by the consumers; (c) “backward-oriented” innovations, based on the interruption of trends towards advanced polymer-based materials in car making.

For both outcomes (a) and (b) above to prevail, a significant uncertainty associated to “free” FTB is about the actual re-distribution of the financial transfer along the downstream part of the ELV chain. In particular, a free FTB does not guarantee that very low or "zero costs" of incremental dismantling are transmitted to the recovery/recycling industries (shredders, material industries) through, for example, very low or zero prices for dismantled materials. If incremental "zero costs" arising to dismantlers from FTB are not shared with the other industries in the downstream operations, the creation of new recovery/reuse/recycling markets could be very difficult.

In principle, a recycling fee/subsidy scheme can alleviate some possible shortcomings of free-FTB. The recycling fee/subsidy is not freely established by dismantlers as it is established by fund administrators at a level corresponding to estimated (net) incremental dismantling costs (see the Appendix). If the recycling subsidy is distributed also to recycling industries other than dismantlers (as in the Dutch scheme), the latter can share the benefits of the financial transfer and have the incentive to contribute to the creation of new recycling markets. Finally, only consumers do pay the financial transfer (as in the Dutch scheme) while carmakers do not pay for ELVs. The reasons for distribution conflicts between carmakers and dismantlers/recyclers emerging with free-FTB can be eliminated by a recycling-fee scheme.

If recycling-fee schemes could alleviate cost-benefit distribution problems of free-FTB and carmakers have to pay nothing in such schemes, it may seem paradoxical that German carmakers, i.e. the most active in the debate on ELV regulation, are strong opponents of the Dutch recycling-fee scheme while preferring a form of FTB and, and at the same time, they oppose the free-FTB of the EU Directive (see Schenk 1999). German carmakers’ preference for a system in which they should pay something comes from the ways the two different systems could be implemented in practice rather than in principle. In particular, the preference seems to arise from the alleged adverse implications of the recycling fee as implemented in the Netherlands, and the possibility to arrive at forms of “controlled FTB” schemes, in particular inside VAs.

81 If the fee should have to be imposed on carmakers, they could transfer it on new cars price very easily.
The weaknesses of the recycling fee and its Dutch application are alleged to arise from the fully-administered working of the system, the creation of subsidised markets, and their potential disincentive for innovation (see Schenk 1999 and personal communications from carmakers). First, with a recycling fee the possibility of a positive ELV price would be ruled out (as it is with free-FTB). Second, if first owner pays, then the last owner would not have incentives to make good car maintenance to receive a positive price for the ELV. Third, dismantlers and recyclers, by being repaid in full for their incremental costs, would not have the incentive to innovate and might do dismantling/recycling at high costs. Fourth, a recycling fee system as the Dutch one could create the possibility of frauds if controls are not enough strong (and then expensive). Fifth, the Dutch system, by generating low-cost materials for recycling, can create spillovers on European recycling markets—an effect similar to that emerged in recycling markets for packaging materials during the 1990s. Against these criticisms, a recycling fee scheme could reduce the transaction costs that can make the last-owner unable to actually receive reimbursement in a FTB system, it could arrive soon at practical achievements in terms of recycling targets (as in the Netherlands), and it could rapidly gain a country-level coverage (personal communications from ARN).

Further to the aversion for an administered system, the German carmakers' preference for a form of FTB is based on the greater flexibility of FTB in terms of practical application. In particular, instead of being freely established by dismantlers, FTB may be subject to a “conditional application” depending on the features of ELVs to be dismantled. Two examples are the condition about the age of the ELVs (less than 12 years) included in the German commitment and the conditions about the starting date and the technical state of delivered ELVs included in both the German and the Swedish schemes (and partly in the Council's Common Position 1999). These conditions create a form of “controlled FTB” that could reduce some possible distortions of “free FTB” discussed above, although it does not solve the issue of incentive transmission to downstream material recycling.

A general possibility of controlling FTB arise with its integration in VAs in which dismantlers and the other industries are subject to reciprocal commitments defining an explicit task distribution, i.e. an implicit cost/benefit distribution (see Par. III.6.3.). On the practical side, dismantlers and recyclers in many European countries are increasingly involved in VAs with no (explicit) economic incentives or "controlled" forms of FTB recently introduced (and still not at work). In many countries, legislation allows car dealers to receive ELVs to be transferred for treatment at authorised dismantlers and a systematic preference for dismantlers in the carmakers’ network (or in the VA) can then arise. The actual formulation of FTB mechanisms inside VAs – in particular well-developed VAs – can create incentives and cost/benefit distribution very different from the free FTB of the 1997 Directive proposal. In this case, the innovation incentives must be considered in the framework of the incentive structure of VAs and industrial networks. It can be noted that the formulation of FTB in the Common Position 1999 is no more a form of “free” FTB and it allows bargain to occur for the definition of car industry’s contribution to incremental costs of ELV treatment.

82 On the forms of transaction costs associated to FTB see Palmer and Walls (1999).
In essence, FTB and recycling fees have different initial cost-benefit allocations that can generate different incentive structures and innovative reactions by economic actors. However, both can have uncertain effects on innovation. In the case of FTB, the critical point is the possible difficulty to redistribute the incentive placed at the dismantling stage across the ELV chain to achieve actual recycling (downstream) and increasing recyclability (upstream). A different incentive structure can arise from forms of "controlled FTB" outside or inside VAs. In the case of recycling fees, critical points are the possibly high administrative cost, the excessive reliance on the ability of the scheme-managing institution, and the lack of "recyclability" incentives given that the car industry does pay nothing.

While there is not yet empirical experience on the working of FTB, the Dutch system offers empirical evidence on the working of a recycling fee. It suggests a possibly great effectiveness of the scheme in achieving specific recycling targets. The Dutch scheme, however, is questioned for its alleged high cost and for its possibly limited ability in creating complete material-recycling loops due to the little integration with the car industry, and then limited feedbacks on "recyclability" (see Part II). It is therefore questioned on the ground of cost-effectiveness. Furthermore, although a recycling-fee scheme fulfil the 1997 Directive proposal’s requirement that the last owner have not to pay for ELV, the consumers will pay in any case and it could be questioned if such a scheme fulfil the "extended-producer-responsibility principle".

III.6.3. Incentives from voluntary agreements

The current state of VAs in European countries has been summarised in Part I and analysed in detail in Part II. The possible role of VAs as a policy instrument can be considered from two points of view: (a) the way they can influence innovation through their incentive effects, and (b) the way the introduction of EU Directive might change their incentive structure starting from their current state.

In the ELV policy debate, VAs are considered to represent the “shared responsibility” approach as opposed to the “producer responsibility” approach represented by economic instruments. Voluntary agreements, however, are not fully comparable to other policy instruments. Their incentive structure is not standardised and it is, instead, tailored to a problem and defined by specific reciprocal contractual commitments among actors that include not only cost-sharing but also benefit-sharing. The latter can be direct economic benefits but can also be externalities, as in the case of knowledge and capability externalities emerging from the country-level case-studies (see Par. III.2). Furthermore, the dominance of technical commitments in ELV agreements greatly limits their transparency in terms of cost-benefit implications for the different participants. The analysis of incentive structure of VAs, therefore, can be limited to some general elements emerging as "common" to the different, and sometimes specific, formulations of VAs in the different countries.

In the innovation perspective, the most important incentive property of VAs is that they can put in a framework of inter-industry cooperation a set of actual and potential economic conflicts.
between the actors involved. In this way they can create a (formal) system of cross-controls between industries.

Many innovations for RRR target achievement are technically interdependent, in particular along the "material-market creation path", but the allocation of their cost-benefits can be conflictual. Advances in DFR/DFD, for example, can give rise to conflicting interests of the material industries, e.g. different polymers. The possible increase of plastics recyclability can support the long-term trajectory of polymer-based materials at the expenses of metals. Increasing dismantling can decrease the amount of valuable materials treated by shredders, while, depending of various factors, it might increase the potential amount and costs of ASR to shredders. The development of ASR recovery (material and energy) can reduce the role of dismantlers while indirectly favouring polymer-based materials, then favouring some industries at the expenses of others.

In this situation, economic instruments, as FTB and recycling fees, can amplify the potential conflicts because of the unwillingness or the impossibility of transmission of the incentives placed at a specific industrial phase to the other industries having innovation responsibilities. VAs, instead, by gluing all the actors together through the contractual task allocation targeted to technically defined achievements, may introduce a form of reciprocal control between the different interest involved, and can potentially spread innovation incentives across the ELV system. In particular, all the single actors will try to maximise their individual net benefits, but the interdependency between partial innovation in the path towards VAs objective achievement creates the shared interest that all the actors are in the condition to work in the appropriate way. The weakness of one actor can impair common achievements. It is unlikely that one industry can participate to the agreement at zero cost or enjoying extra-profits at the expenses of other actors. The car industry, for example, can use the leadership it has in most VAs to pursue its own cost minimisation. If the agreement has specific quantified RRR targets, however, carmakers have the interest to support the development of an efficient and regulation-complying dismantling industry and, to this end, they cannot avoid investment costs in suitable design for dismantling.\footnote{It must be noted that part of the “power” of the car industry could be exercised outside voluntary agreements and even in presence of detailed regulation on ELV. This is the case of technical specifications, e.g. requirements on non-hazardous materials in the components, imposed by contracts to upstream supplier industry, which is a trasmission of “producer responsibility” independent from the existence of a VA.}

In a framework of balanced and cross-controlled interests, the possible introduction of economic instruments, as “controlled FTB”, rather than creating distribution conflicts, can have the complementary role of a second-level incentive possibly reinforcing the VA incentive structure when the latter reveals to be weak. Furthermore, the introduction of a controlled FTB can help in maintaining the problem of costs and benefits of ELV innovation at the level of industry, thus reducing the possible role of consumer as the payer of last resort. Finally, by being tailored to national/local specificities (see Par. III.3), VAs can push to the organisation that is most suitable to national contexts and then possibly less expensive in terms of total cost of targets’ attainment.

\footnote{\footnotetext}
In essence, VA could be credible as a way for balancing the competing industrial interests and distributing innovation incentives among industries. In particular, by avoiding the creation of extra-profits to some actors, VA can prevent from free riding by some actors as well as conflictual reactions not favourable to targeted innovation.

The positive incentive properties of VAs, however, cannot be taken for granted in practice because they emerge in a process that is far from completed in all the European countries. As emerging from Part I and II, the VAs in European countries are similar in terms of targets and commitments, but their state of development, achievements, legal status, and organisation is very differentiated —ranging from formal and still ineffective agreements to well-organised systems that already achieved practical results.

A cross-comparison of the actual incentive structure emerging from different agreement is very difficult. At the level of agreement organisation, the same factors seem to work differently in different national contexts. The presence of a “national” car industry did influence the formation and the completeness of VAs, also in terms of the material loop, but it did not influence in the same way the features of the agreements, e.g. the German scheme introduced a form of FTB while the French one does not have economic instruments. The features of agreements are differentiated even between countries without a national car industry. Some countries with very active environmental policies (e.g. Denmark, the Netherlands) adopted schemes favourable to some specific industries in the ELV chain (i.e. dismantlers and recyclers), while other countries organised VAs very similar to countries with a “national” car industry.

The regularities are weak also in terms of the incentive structure possibly leading to effectiveness. As emerging from Part II, even company-level initiatives or country-level agreements with no explicit forms of economic incentives and weak regulatory framework have been able to reach practical achievements on recycling and recovery rates. The positive results of these agreements seem to be dependent on: (a) a large industrial participation; (b) the investments in DFD/DFR by the car industry; (c) the successful creation of dismantling networks; (d) a sufficient experience allowing a deeper learning process. However, the Dutch system, which includes a recycling fee in an administered system, rapidly achieved its short-term targets – but the latter can be considered as narrowly focused in many respects.

In essence, different formulations of the agreement seem to contain an incentive structure favourable to innovation, and there is not enough sound empirical evidence to establish what is the “ideal” VA formulation as well as the role of both economic instruments and legislation. Whatever the evaluation, it cannot be conclusive. On the one hand, most agreements did not still achieve RRR targets as those required by the EU Directive, and this can leave rooms for the proponents of legislation and economic instruments as necessary (or even sufficient) conditions for target achievement. On the other hand, the entry into force of the EU Directive will change the framework of national and industrial VAs thus probably changing their working to some extent.
In the Common Position 1999 VAs are allowed as a way the Member States can comply with the most important provisions of the Directive, including the details of FTB mechanism. Most Member States have some forms of VA in place and, therefore, it is reasonable that VAs will be maintained but adapted to the requirements of the Directive.

RRR targets will become legally binding in national transposition — thus changing the currently non-statutory status of RRR targets in most national VAs — and they will include targets for mechanical recycling. The latter are those more closely justifying the development of agreements between different industries aimed at the “material market creation path”. Furthermore, the Common Position requires enforceability, evaluation, and procedure for non-compliance, thus introducing in a formal way the threat of detailed regulation if VAs will not attain the objectives.

Legally binding targets and non-compliance procedures may represent a strong incentive for VAs. They create an explicit economic dividend for VAs, i.e. the possibility to avoid expected costs of detailed regulation. Since their beginning, one of the main objectives of VAs was to avoid the expected costs of formal regulation with binding targets. The Directive regulates many aspects of ELV, but it formally reintroduces this possible dividend. The latter is less than desired by industry, but it can be still significant and can give impulse to the acceleration of practical achievements.

The variety of VAs will be probably reduced and some features will become more standardised across countries, at least for the minimum requirements that have to be transposed at the national level. The VAs will therefore move on a common ground of objectives and framework regulation, while maintaining some degrees of flexibility in the latter at the national level.

A change in the role of VAs can arise. Through VAs, industry has pursued demonstration effects towards policy-making. With the EU Directive in force and national legislation allowing VAs with non-attainment provisions, VAs will have only the role of achieving targets and other provisions in a cost-effective way. Their demonstration effects, therefore, will become the relative cost-effectiveness of different organisational solutions and instruments included. It is likely that the best-organised VAs will be successful and they can supply demonstration effects to other industrial/national schemes at less-developed stages. Although within the boundaries defined by the differences of national economic environments, this can pave the way to the selection of the best organisational and technological approaches to ELV, and can stimulate a “race to the top” by the different countries/companies.

84 “Provided that the objectives set out in this Directive are achieved, Member States may transpose the provisions set out in Articles 4(1), 5(1), 7(1), 8(1), 8(3) and 9(2) and specify the detailed rules of implementation of Article 5(4) by means of agreements between the competent authorities and the economic sectors concerned. Such agreements shall meet the following requirements: (a) agreements shall be enforceable; (b) agreements need to specify objectives with the corresponding deadlines; (c) agreements shall be published in the national official journal or an official document equally accessible to the public and transmitted to the Commission; (d) the results achieved under an agreement shall be monitored regularly, reported to the competent authorities and the Commission and made available to the public under the conditions set out in the agreement; (e) the competent authorities shall make provisions to examine the progress reached under the agreement; (f) in case of non-compliance with the agreement Member States must implement the relevant provisions of this Directive by legislative, regulatory or administrative measures” (Council of the European Union 1999, Art. 10.3).
III.7. Economic impact of regulation

The policy debate on ELV regulation focused on two issues: (a) costs and benefits of regulation and their distribution; (b) competitiveness and competition problems arising with regulation (i.e. competitiveness disadvantages for EU products) or to be solved by regulation (i.e. harmonisation within the Single Market). Both issues have been much emphasised and poorly explored in a rigorous way.

III.7.1. Costs and benefits

The ELV Directive does not depart from a general situation of limited efforts on cost-benefit analysis (CBA) of EU environmental policies. According to the Treaty (Art. 174, former Art. 130R), EU environmental policies should be submitted to some form of evaluation of the costs and benefits of action and non-action. The number of EU environmental regulations submitted to ex ante CBAs, however, is limited and the extent CBA results actually influenced regulation making remains a moot point (see Pearce 1998a). CBA concepts and methods are, instead, regularly applied to environmental regulation in the United States and, partly, in the United Kingdom (see Pearce 1998b). CBA of environmental policy can actually be subject to methodological issues and empirical limitations. In addition to normal difficulties of environmental evaluation, additional difficulties may arise when innovation and long-term dynamic reactions are taken into account (see Quadrio Curzio and Zoboli 1998). Furthermore, cost-benefit distribution among social actors can be a critical aspect of environmental policy and, given that the environment is an actor with no voice, arbitrariness and biased preferences can prevail in CB-distribution appraisal. For these reasons, the direction of cost-effectiveness evaluation of alternative policy approaches and policy-impact analysis could offer feasibility advantages over CBA (see Zoboli 1999).

Explicit analyses of the cost-benefit associated to EU Directive on ELV are not available. The explanatory notes of the Directive proposal 1997 claim that net costs associated to the Directive should be low, also in consideration of the possible benefits for recycling industry and the associated new jobs (see European Commission 1997). One argument for the limited cost-benefit analysis effort associated to the Directive is that it would be too difficult and imprecise in many respects. In these conditions, other principles should apply (i.e. preventive action) that make the existence of a positive cost-benefit balance a non-necessary and non-sufficient condition for Community action (see Onida 1999). In the case of country-level legislation and voluntary agreements, cost accounts are available only for the Dutch scheme (see ARN 1998) but they are direct costs and cannot be considered as a social cost-benefit analysis. For other countries with legislation/VA, only the accompanying notes of the German legislation on ELV claim that, in consideration of various factors, the legislation should not create high costs to industrial sectors – which is again not a social cost-benefit consideration (see Federal Ministry of the Environment 1997). Only estimates and summary data of some specific cost items have been produced in the 1990s. The possible cost of FTB as formulated in the 1997 Directive
proposal for the car industry have been estimated at 56 billion DM by ACEA based on a recycling cost of 250-350 DM per vehicle. Other estimates of FTB cost for different car brands in different countries have been produced by Org-Consult (personal communications). Some data are available for the R&D costs supported by cooperative projects on ELV (see Par. III.2). Only scant figures are publicly available on the company-level investments on DFD and DFR, on the start-up CBs of ASR energy recovery projects, on the costs-benefits of the organisation of dismantling/recycling networks. Explicit cost-benefit evaluations have not been made for the policy choice of limiting ASR energy recovery and even the environmental superiority of this preference is questioned by industry's studies.

Actual limitations to cost-benefit estimates of ELV regulation arise from the critical role innovation has in the problem.

ELV policy objectives and targets could have been established by defining marginal costs and benefits of different rates of ASR “non-landfilling” then deriving optimal non-landfilling rates at which net social costs are minimised. The costs and benefits functions required for such an optimal recycling exercise, however, depends on innovation paths. The definition of optimal recycling would be an exercise on cost-benefit evaluation of alternative routes of the innovation process and the optimal rate of ASR non-landfilling would have been different from country to country. As in most environmental policy problems, the challenge of evaluating optimal targets for ELV starting from the associated CBs has been escaped by both policy makers and industry, and the way the “consensus” component of RRR targets was defined has been described in Par. III.5.3. The issue of targets optimality is therefore open. On the one side, industrial actors stress that the capabilities of national ELV management infrastructures to reach the targets can be very differentiated and targets can be too ambitious for some countries. On the other side, some degrees of national flexibility are allowed by the formulation of RRR targets, even though they are generally demanding for all the countries. We shall turn on the problem in the framework of harmonisation.

Significant difficulties arise also in cost-effectiveness analysis, i.e. comparison of relative net costs of different policy approaches to achieve established targets.

Different innovation paths are possible and the initial CBs distribution can influence actors' choice about them. Each path can have different total net social costs deriving from the complex combination of different costs and benefits. The list of CBs associated to “material market creation” path can include, for example: the R&D costs on DFD/DFR by carmakers and the possible benefit of material regime simplification; the cost for industries producing material subject to substitution and the benefit for the producers of the substitute materials; the adaptation cost supported by regulation-complying dismantlers and the benefit they gain at the expenses of competitors; the environmental and economic benefits for landfilling reduction. In the “energy market creation” path, costs can arise, for example, to the suppliers of energy for which ASR-derived energy can substitute, and benefits can arise for shredders that save landfilling costs while gaining from selling ASR. Each technological route for achieving the targets can have not only a different net total cost but also a different cost-benefits distribution among industrial

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85 Financial Times, September 8, 1999. The request to ACEA for additional details was not successful.
actors. Furthermore, many costs and benefits might be shifted to other actors through the market mechanism and price system during the innovation process.

By influencing the choice among innovation paths (see Par. III.6), regulation provisions can influence both the total net cost and its distribution between actors. Some policy provisions can directly influence innovation and the associated costs, as in the case of heavy-metals limit values that imposes R&D costs as well as gains and losses for different metal producers. Other policy instruments can influence indirectly innovation and the choice of the path by inducing specific incentive structures and reactions by actors. This is the case in particular with economic instruments, as suggested by the discussion on FTB and recycling fees in Par. III.6. They can induce an impact cost allocation (incentives) that can influence innovation choices in the attempt to absorb and/or redistribute net costs. Through these reactions, a final net cost distribution and a final total net cost (innovation path) can be achieved that can differ in an unpredictable way from that initially pursued. The same arguments can also apply to policy approaches based on inter-industry agreements (see Par. III.6).

The obvious conclusion is that both total net-cost and cost-benefit distribution of regulation are very difficult to evaluate as long as the innovation paths are still open and the incentive effects associated to different policy instruments are not fully operational. It must be stressed that specific cost-benefit items, e.g. FTB costs, must not be confused with the social net cost of ELV regulation because they are mainly impact-cost that define the initial burden (or benefit) of regulation provisions on some specific industries and actors. The cost-benefit redistribution and the corresponding incentive effects on innovation may then develop along the lines described in Par. II.6 for both direct regulation and economic instruments.

These difficulties cannot justify the lack of efforts on CBA and/or cost-effectiveness analysis of different ELV policies. The strong controversies surrounding environmental and economic aspects of ELV policy would have suggested investing more in this field of analysis to achieve a deeper understanding of the complex economic relationships in the ELV chain.

### III.7.2. Competitiveness and competition

Competitiveness’ loss is one of the arguments often raised against ELV policy because EU Directive has no parallel in the legislation and action of other major car-producing areas (see Part II). International competitiveness’ loss can be an important element in social cost evaluation of ELV regulation because it can be directly translated in terms of GDP losses. Despite the lacking quantification, ELV policy is likely to have impacts on short-term costs of industries in the ELV chain, and additional production costs and/or higher car prices can negatively influence the competitiveness of EU products compared to the United States, Japan and other producing regions.

An international competitiveness effect of ELV policy cannot be ruled out in principle, but its practical significance is difficult to evaluate. A first point is the possible level of regulation-induced price-competitiveness disadvantage. If the level of the Dutch recycling fee (68.2 Euros
per car) is taken as an indicator of the possible price disadvantage of European cars following
the introduction of ELV policies, the competitiveness effects could be low, although
differentiated among car classes. If the appropriate level is considered the FTB cost estimated
by ACEA (250-350 DM per car) as translated on car prices, the competitiveness effect could
be more significant. In both cases, a point to be considered is that car is par excellence a
differentiated product, and price competitiveness can have a weak meaning even inside the
same car class, as suggested by the often very large price range in the same car class.

Other aspects possibly influencing the international competitiveness effect of ELV regulation are
the globalisation of the car industry and the problem of market access. They can be considered
at two levels: (a) industrial strategies, and (b) international standardisation and trading rules.

The European car industry is highly and increasingly global in terms of production localisation,
trade flows, and companies' control through foreign direct investments (see Part I). In a global
industry, it is likely that one single production standard for a specific aspect will prevail in order
to enjoy economies of scale and access to all the national markets wherever production is
located, i.e. each car model should be “global” in its market segment. The prevailing production
standard is likely to be the more demanding one in order to have market access to the area with
the highest standard, especially if the latter is Europe, and because of the shared expectation
that it will become the global reference standard. Other areas of environmental policy suggest
that the highest standard gradually became the international reference, in particular when
important countries and/or producers perceived a leadership advantage. Because of the
importance of Europe and European producers in the global car industry, it is likely that the
European standard in terms of car recycling/recyclability and ELV management will gradually
become the international reference. The attitude of Japanese and American car producers on
ELV management (see Part II) reveals their concerns for a possible loss of market opportunities
in Europe as a consequence of ELV regulations. Japanese carmakers are paying a great
attention to future obligations and organisational solutions for their ELVs in EU countries
(personal communications by Org-Consult).

Even in the case that industrial strategies are convergent, the “unilateral” adoption by EU of
stringent ELV management and car recyclability standards might rise issues in terms of access
to European market and international trading rules. The Directive provisions applies to cars “put
on the market”, registered, and deregistered in Member States, and then it does not discriminate
between car produced domestically and those produced in other countries. In this way, cars
produced in non-EU countries are implicitly submitted to the same rules and technical standards
as those produced in the EU. Japanese cars sold in the EU must be recycled/reused/recovered
at the same rates as German cars produced and sold in the EU, and American producers have
to pay FTB as do EU producers. In terms of product standards, provisions on heavy metals
content and labelling in alloys (Art. 4.2(a) of Common Position 1999) also applies to cars of non-
EU make “put on the market” in Member States. The same applies to future regulation of RRR-
ability (Art 7(4)) which is could be interpreted as a trade barriers by non-EU producers, in
particular in the case that regulation in Japan and the United States should evolve towards
standards which differ from those established by the EU. The GATT-WTO rules allow
differentiated technical standards and guarantees the protection of domestic environment from
imported goods (Art XX.b and XX.g) but various disputes have risen on these grounds in the

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Regulation and Innovation in the area of End-of-Life Vehicles: Innovation process and Regulation

recent past (see WTO 1999, OECD 1996). If these issues should rise, ELV may become an additional open area in the international standardisation of automotive products –already subject to the difficulties induced by globalisation (see Audet 1998).

ELV regulation raises a different set of issues in terms of competition in the Internal Market. Harmonisation is one of the key arguments on which the EU Directive proposal has been put forward. The diversity and different degree of development of ELV management initiatives (VAs and legislation) in Member states at mid 1990s have been considered able to create distorted competition (European Commission 1997). In general, the existence of rigorous arguments for the centralisation of environmental policies at the EU-level can be questioned (see Oates 1998) but the harmonisation objectives of ELV Directive cannot be disregarded.

A first point is the need of technical standards on ELV treatment. The need to avoid a “race to the bottom” by different countries by establishing minimum common requirements for ELV treatment facilities in all Member States could be sufficient to justify an EU Directive. Technical and environmental requirements on ELV treatment are, in fact, a key element of industrial VAs and national legislation in force, and they are a ground of consensus between industry and regulators. A large part of ELV-related environmental externalities arise during treatment before ASR landfilling. The existence of many treatment facilities that are not participating to VAs’ commitments and countries where regulation of treatment facilities is weak (or weaker compared to other countries), creates the risk that ELV treatment is less demanding in some Member States and/or facilities in the same country. Distorted competition based on low technical/environmental standards could arise and it can create both undesired ELV transboundary flows and economic difficulties to higher-standard facilities/countries. A common set of minimum technical requirements can help also the development of national and industrial VAs and, by reducing the incentives for a race to the bottom, common rules can help a race to the top on treatment standards.

The second point is the possible “dis-harmonisation” content of some EU Directive provisions. The problems can be associated to economic instruments and FTB in particular. The “free-FTB” of 1997 Directive proposal leaves a complete freedom to dismantlers to establish the amount of FTB as the negative price for ELVs (see Part III.6.2 and Appendix). The Directive imposes an higher rate of dismantling, i.e. higher operating costs, and the (negative) price of ELV with a free-FTB after the Directive could have changed in an unpredictable way (see also Zoboli 1998 for a discussion). The prices for ELVs are very different also at present in the different countries but “free FTB” would have created a regulation-induced component of variability. The FTB formulation in Common Position, which allows each country to establish the details of the mechanism, does not solve the problem. Some countries might adopt free-FTB, other countries might establish fixed share of incremental costs allocated to car industry, and other countries might introduce “light” or conditional forms of FTB.

The third point is the harmonisation content of common RRR targets in all European countries. Member States have different capabilities for ELV-management and innovation, and the Directive targets are not “optimal” targets for some countries that can have greater difficulties (i.e. costs) in reaching them compared to other countries. The question is the possible desirability of differentiated RRR targets for different countries. Recent international policies for
transboundary pollution or global commons adopted differentiated targets for different countries. The case of ELV waste is different. Transboundary externalities arise with intra- and extra-EU flows of ELVs and ELV waste and they can be reduced by preventing the treatment ELVs in locations different from those in which they arise. The principle of proximity should apply. The adoption of differentiated RRR targets, instead, might create incentives to move ELV treatment in countries with the less demanding national targets, e.g. non-specific targets for mechanical recycling, and they would be questionable in terms of competition and Single Market. Although uniform EU targets can be largely different from the “optimal” targets for some countries, the targets cannot be confidently differentiated without the risk of distorted competition from regulation.

On the practical side, however, there can be other arguments both against and in favour of uniform RRR targets at EU level. On the one hand, the present conditions of ELV treatment are quite different in different countries but there are not large intra-EU flows of ELVs for treatment while extra-EU ELV flows are mainly for reuse as second-hand cars (see Part I). Transportation costs and minimum uniform requirements for ELV treatment across EU can pose a limitation to ELV trade for treatment that could hardly be reduced by differentiated targets – unless differentiation is very strong. On the other hand, the international profile of car industry operations can reduce the non-optimality of uniform RRR targets across EU countries. Multi-country production and distribution networks of car companies can favour increasingly interrelated ELV treatment systems in the different countries. International cooperation initiatives by carmakers, as the BMW-FIAT-Renault agreement for sharing the collection-dismantling networks in the different countries (see Part II) can be considered as the prototype of a EU-level network making the conditions of ELV treatment more homogeneous across countries.

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86 This is the case with the 1997 Kyoto protocol in the framework of the 1992 Convention on climate change and the 1994 Protocol on further reduction of sulphur oxides in the framework of the 1979 tranboundary air pollutants convention.
APPENDIX: The market for ELVs, free-take-back, and recycling fees

A.1. Free take-back

Figure A.1 and A.2 illustrate the comparative statics of FTB in the market for ELVs. In order to simplify the analysis, we assume that ELVs arising at a specific date have all the same age and technical features, there is just one (national) competitive market, and just one equilibrium price for ELVs at which transactions take place. For presentation convenience, the negative portion of the price axis is placed upside in the figures. The variable for quantities is the number of ELVs delivered to dismantlers by last-owners.

Figure A.1 describes an ELV market with a negative equilibrium price before FTB (e.g. the German market). The supply curve for ELVs by last owners (So) is downward sloping for negative prices (i.e. the propensity to deliver ELVs will increase for decreasingly negative prices) and become vertical for zero to positive prices at the maximum number of cars becoming ELVs at that time (i.e. last-owners will be ready to deliver all their ELVs for non-negative prices). The demand curve for ELVs by dismantlers (Do) will be upward sloping starting from a positive price. The most efficient dismantlers (low costs of treatment) will be ready to pay a positive price for ELVs, but, in order to treat an increasing number of ELVs, the dismantling industry requires lower and lower positive prices up to negative prices for large quantities (i.e. marginal quantities will be treated by dismantlers with higher operating costs). The equilibrium price (po) will be negative (by assumption) and the quantity of ELVs treated (qo) will be less than the maximum available number (i.e. some ELVs will not be delivered).

We assume that FTB (i.e. reimbursement of last owners by carmakers for negative prices of ELVs) is introduced together with the obligation of higher dismantling rates (i.e. incremental costs) by dismantlers. The latter are free to establish demand prices for ELVs. Let us assume for simplicity that incremental dismantling costs are net costs, i.e. additional dismantled parts/materials have not a market value. With FTB, both supply and demand curves will shift. The possibility of reimbursement in a FTB scheme will induce the last-owners to deliver all their ELVs and the supply curve will shift rightward to become SFTB (i.e. vertical at the maximum number qFTB for whatever price to be paid or received). Due to the freedom to establish the demand prices for ELVs, the change of the demand curve of dismantlers cannot be defined exactly ex ante. The increasing costs of incremental dismantling will surely push upward the demand curve to cover the incremental costs, i.e. the availability to pay ELVs at positive prices will decrease. Because of FTB, the price at which ELVs will be accepted by dismantlers is likely to become increasingly negative.

87 Obviously, in the real world, ELVs at a certain date have different ages and technical features, the market is local, and pays different prices for different ELVs features. The proposed scheme, therefore, can approximate a local market for one specific type of ELVs of the same age where competition between dismantlers pushes at one single equilibrium price.
It is likely that the demand curve will start at zero prices (i.e. no dismantler will pay a positive price for ELV) and will increase for increasingly negative prices (DFTB). Provided that last owners will be reimbursed for whatever price he/she has to pay to dismantlers, and the payer of FTB (i.e. carmaker) do not participate to the transactions, there are not boundaries to the upward shift of the demand curve ("free" FTB). The exact position and slope of the demand curve is therefore not defined ex ante except for the component related to actual incremental costs of dismantling. The equilibrium price could be \(-p_{FTB2}\) or higher (or lower!) while the equilibrium quantity will be \(q_{FTB}\), i.e. the maximum number of ELVs available at that time.

In terms of cost-benefit balances, the environment will gain with FTB because it is reasonable that no car will be abandoned and an increasing amount of materials/parts will be dismantled (and hopefully recovered/reused/recycled). The dismantlers will reasonably have all their incremental costs covered by payments they receive from last-owners (area \(-p_{FTB2} \times q_{FTB}\) and the possibility they can enjoy “free lunches” by receiving super-transfers cannot be ruled out. Last owners will gain compared with the non-FTB situation (when they paid area \(p_0 \times q_0\) because they will be fully reimbursed and will not actually pay whatever negative price established by the dismantlers. Carmakers will support all the incremental costs and the possible free lunches (if any) through transfers to dismantlers (area \(-p_{FTB2} \times q_{FTB}\).
Figure A.2 illustrates the same mechanism for initial market equilibrium at positive prices for ELVs without FTB (e.g. the French market). Two main differences arise compared with the previous situation. The demand curve by dismantlers will be lower because they are assumed to be ready to pay higher prices for ELVs (i.e. positive prices even for large quantities). The equilibrium quantity treated can be presumed to be at the maximum level $q_0/q_{FTB}$ even in the initial situation (i.e. it can be presumed that ELVs are not abandoned given their positive equilibrium price).

**Figure A.2. FTB introduction with initial positive equilibrium price for ELVs**

The introduction of FTB will work in the same way as described above but the cost-benefit implications will be different. The environment will gain only for incremental dismantling (and reuse/recovery/recycling) because all the ELVs are presumed to be already delivered before FTB. The transfer to dismantlers will be paid by both last-owners and carmakers. If, as depicted above, with FTB and increasing dismantling costs, the dismantlers will no more pay positive prices to car last-owners, then the last-owners will have an opportunity cost (corresponding to the area $+p_0 \times q_{FTB}$) which is a transfer to dismantlers. Carmakers will pay a transfer to dismantlers corresponding to the equilibrium negative price $-p_{FTB}$ applied to the number of cars accepted for dismantling ($q_{FTB}$).

To simplify the analysis, we have not considered that, in both situations, increasing dismantling rates may give rise also to benefits for dismantlers (together with costs) if they are able to sell dismantled components, parts, and materials at positive prices. Although it does not
change the fundamental mechanism depicted above, the introduction of this possibility enlarges the uncertainty about the cost-benefit implications. It involves, in fact, other markets and in particular those for dismantled parts to be recovered/reused/recycled and the problem of prices that may prevail in those markets. One possibility is that FTB covers all the incremental costs of dismantling and, then, dismantled materials-parts can be made available at “zero prices” to the downstream recycling industries. Another possibility is that FTB do not cover all the incremental costs, and a positive price is needed for dismantled materials-parts. Another possibility is that, although FTB covers all the costs, dismantlers are able to receive positive prices for dismantled materials-parts. With a complete freedom of establishing FTB levels, all the possibilities are open and can have different implications on the development of recycling chains and the “material market creation” path.

A.2. Recycling fees

The analysis of a recycling fee scheme can be done along the same lines, for example in the case of a market with a negative equilibrium price (-p) for ELVs in the initial state (Figure A.3). We assume that, as in the Dutch scheme, the recycling fee is a fixed monetary amount levied on the price of new cars and paid by first-owner. It is collected by a fund and we assume that it is paid as a premium to dismantlers (and, for simplicity, to neither last-owners nor recyclers) to cover the incremental costs they should support for increasing dismantling. Last owner will have to pay (receive) a zero price for delivering to dismantlers (i.e. the take-back is free).

The introduction of recycling fee corresponds to the creation of an administered market for ELVs managed by one institution that decide the unit fee to be charged on first-owners and the transfer/premium to be paid to dismantlers. The two variables must be obviously related if the system have to be financially self-sustainable. If we start from an equilibrium negative price (-po), the introduction of the fee-based system, by freeing last owners from possible payment to dismantlers, should bring the number of delivered ELVs to their maximum amount (qRF) by shifting supply curve from So to SRF. If the financial fund cannot accumulate excess money or debts, the transfer to dismantlers per each ELVs should correspond to the fixed unit recycling fee levied on new cars, and both can be assumed to correspond to the net incremental cost of incremental dismantling rates. The fee, therefore, depends on the dismantling target-rates adopted by the manager and on the calculation (or the bids made in an auction system) of net incremental dismantling costs. The unit fee will be also the equivalent of a (negative) equilibrium market price for ELVs (-pRF in Figure A.3).

The cost-benefit distribution of the recycling-fee system includes a positive effect on the environment if, starting from negative-price equilibrium in which some ELVs were abandoned in the environment, the last-owner can now deliver at zero price to dismantlers and will not abandon the old car. The other positive environmental impact will come from increasing dismantling (and hopefully increasing recycling/recovery/reuse). The first buyers of new cars will support the cost of the transfers to dismantlers that will be administratively fixed (area -pRF x qRF). Dismantlers, in fact, do not have the possibility of establishing in a discretionary way the (negative) prices for ELVs, as was the case with FTB. Last car-owners will be better off than in the initial situation to the extent they have not to pay for delivering ELVs. However, it is
reasonable that the set of last-owners approximately corresponds to the set of new cars’ buyers in a normal renewal process of the car stock, and car consumers as a whole will pay the full net amount of calculated incremental costs of dismantling. Carmakers, instead, will have to pay nothing.

**Figure A.3. Recycling fee introduction with initial negative equilibrium price for ELVs**

Different initial assumptions can be made. If we assume that the initial situation is one of equilibrium positive price for ELVs, the benefit/cost balance will be different. The recycling fee should not change the quantities dismantled that should be already at their maximum number (qRF). Last car owners, then, will have an opportunity cost with recycling fee because, in the new situation, it is unlikely that dismantlers will pay a positive price for ELVs. Another different assumption could be made on the distribution of recycling premiums. If it is redistributed also to recyclers, as in the Dutch scheme, the benefits will be shared by different industries in the downstream reusing/recycling/recovery chain. This might reduce the uncertainty about benefit redistribution between downstream industries possibly arising with FTB, but the amount of premium to recyclers will again depend on fund managers’ calculations (or auction bids). Another possibility is to redistribute part of the premiums also to last owners, as in the early Swedish deposit-refund system and the designed Danish system, thus creating a “carrot” to stimulate the delivery of all ELVs. In this way, the cost supported by car consumers as a whole will be reduced, although at the expenses of the premium/transfer available for dismantlers/recyclers. In general, provided that recycling fees create an administered market, most of the re-distribution and incentive effects depend on the way the system is designed and implemented.
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## List of Interviews
*(positions are those at the date of interview/contact)*

### France

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<tbody>
<tr>
<td>Jean Paul Vallat</td>
<td>Directeur du Projet Recyclage</td>
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</tr>
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<td>Pascal Feillard</td>
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<td>Pierre Picot</td>
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### Germany

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<tbody>
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<td>BMW AG</td>
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### Italy

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<td>Eugenio Turchetti</td>
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<td>William Bandinelli</td>
<td>President</td>
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<td>G. Zoccolan</td>
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<td>Eco.Pne.Us</td>
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### The Netherlands

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### Sweden

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<tr>
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<tr>
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<td>Director Environment and Health Care</td>
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### The United Kingdom

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<tr>
<td>Derek Wilkins</td>
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<td>Rover Group Ltd</td>
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<tr>
<td>David Hulse</td>
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<td>ACORD Automotive Consortium on Recycling and Disposal</td>
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*Interviews took place from February 1999 to June 1999. Requests for interviews to some other companies and institutions did not receive reply (see notes to the text).*
## Professional Associations

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<td>Didrik de Thibault</td>
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<tr>
<td>Francis Veys</td>
<td>Director General</td>
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<tr>
<td>Ross Bartley</td>
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<tr>
<td>Hans Herlitz</td>
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<td>Silvain Giraud</td>
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<tr>
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<td>Secretaire General</td>
<td>FEAD, Federation Europeenne Activité du Dechet</td>
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## European Commission

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<td>Robert Strauss</td>
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<td>EC Directorate-General ENTR</td>
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The European Commission JRC-IPTS and Enterprise DG

The impact of EU regulation on innovation of European Industry

Regulation and innovation in the area of end-of-life vehicles

VOLUME II
Technical Analyses

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March 2000

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The views expressed in this study do not necessarily reflect those of the European Commission (EC).
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INTRODUCTION

The mission of IDSE-CNR was to study the relationships between regulation and innovation in the area of end-of-life vehicles (ELV). The required impact analysis included the following aspects of regulation-innovation relationships: (a) the regulation process; (b) initiatives by car manufacturers; (c) links between policy instruments and innovation in ELV; (d) innovation in the car industry; (e) policy performance and recommendations

A preliminary study on regulation and innovation in ELV carried out by IDSE-CNR (see Zoboli 1998) revealed: (i) a systemic profile of the ELV problem in the perspective of regulation-innovation relationships; (ii) strong limitations of the available information base for the research mission. As a consequence, the basic choices of the research study have been: (a) a methodological approach addressing ELV regulation-innovation as a systemic problem, also based on methodological suggestions from the IPTS-JRC project as a whole; (b) a research approach based on direct contacts and interviews with the economic and institutional actors of the ELV system in Europe.

A series of 35 direct interviews and other contacts at the European Commission (DGIII, DGXI, and DGXII), professional associations involved in the ELV problem, and carmakers’ recycling departments were organised. The list of the interviews is enclosed at the end of the Research Report. Some other requests for direct interviews did not receive positive reply. Other direct contacts were possible during the international conference on “Car recycling in Europe” (Munich, March 10th-11th, 1999). In general, the coverage of interviews and contacts can be considered as largely representative, albeit not exhaustive, of the ELV actors in Europe. Interviews and direct contacts supplied a rich set of information and documents (some of them having a limited circulation).

Most of the interviews took place when the EU Directive proposal on ELV of 1997 passed through the First Reading by European Parliament (February 1999) until the Council Common Position (July 1999). Every care has been taken to avoid that this Report was influenced by the positions in the debate about the Directive, as expressed by interviewed representatives of professional association, carmakers, and European policy-makers at the Commission.

The presentation of the research results is structured in two volumes.

Volume 1 (“Research Report”) fulfils the main requirements of the research mission. It is structured in three main parts.

---

1 Technical Annex of IPTS-JRC call for tender for studies on “The Impact of EU Regulation on Innovation of the European Industry” (92/50/EEC - 98/S 75-44736) and contract for the study “Regulation and Innovation in the Area of End-of-Life Vehicles” (No. 14401-1998-10 F1ED SEV IT)
* Part I addresses the ELV problem and policy developments at the European level by depicting: (a) the ELV system and its present state from the environmental, technological, and economic point of view; (b) the policy/regulation initiatives in Member States and the regulation-making process at the EU level. The analysis is open by a short overview of structural changes of the automobile technological system in Europe.

* Part II addresses in details the ongoing initiatives for ELV in single EU15 countries as well as Norway, the United States, and Japan, and focuses the developments taking place in major European car companies as emerging from direct interviews and documents.

* Part III analyses the innovation process and the role of regulation as emerging from Part I and Part II. It addresses in particular the set of specific innovations underway, the systemic features of the innovation process, the existence of different innovation paths, the relationships between regulators and innovators, the role of specific policy instruments. The cost-benefit implications of regulation on ELV are then outlined.

* Main results and policy recommendations are presented at the beginning of the Research Report.

Volume II (“Technical Analyses”) supplies a deeper and more technical examination of innovations in ELV and car recycling/recyclability. The “technical analyses”, that maintain a focus on environmental and economic aspects, can add important elements for understanding the innovative developments that the Research Report puts in the regulation-innovation perspective. Volume II is structured by topics including design for the environment, ELV disposal technologies, automobile material evolution, automobile plastic recycling, as well as other specific aspects of car recycling.

The Report is based on the information available at December 15, 1999 and updated information arising in January-February 2000, e.g. the early results of Parliament’s second reading of ELV Directive.

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2 A detailed analysis of the Swedish case was added to the five detailed country analyses (France, Germany, Italy, the Netherlands, and the United Kingdom) originally included in the IDSE-CNR project.
Acknowledgements

The research work has been carried out at IDSE-CNR (the Research Institute on the Dynamic of Economic Systems of National Research Council of Italy) by: Roberto Zoboli (IDSE-CNR, Project Leader); Giancarlo Barbiroli (University of Bologna); Nicola De Liso (IDSE-CNR); Riccardo Leoncini (IDSE-CNR); Massimiliano Mazzanti (University of Rome III and IDSE-CNR); Sandro Montresor (University of Bologna and IDSE-CNR).

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Analyses presented in the Report have been discussed, in their preliminary version, during the workshops organised by IPTS-JRC for the “Regulation-Innovation” project. In particular, we thank Gerhard Becher, Diana Bredford, Jens Hemmelskamp, Celia Graves, René Kemp, Fabio Leone, Gérald Petit, Keith Smith, Horst Steg and the other participants to the workshops for their comments and useful suggestions. The continuous stimulus and help by Fabio Leone and Jens Hemmelskamp (IPTS-JRC) during the research work is gratefully acknowledged.

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The Report also benefited from the comments to papers on the ELV case-study presented by R. Zoboli at the following conferences and workshop: International Conference on “Innovation-Oriented Environmental Regulation”, IPTS-JRC, ZEW, MERIT, Potsdam, May 27th-29th, 1999; “Recycling Forum” (Working Group C, Research and Innovation), European Commission - DGIII, meeting of November 9th, 1999, Brussels; Workshop on “Ecological Product Policy: Potential Role of the Stakeholders”, European Environmental Bureau, Brussels, December 10th, 1999. Comments received in various instances on the IDSE-CNR preliminary study on ELV (Zoboli 1998) are also acknowledged.

All responsibilities have to be assigned only to the producers of the Report.

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Chapter 1
Design and the environment

1.1 New trends in design

Traditionally, products have been designed to satisfy only functional requirements and specifications. Recently, interest has been generated in designing products that not only satisfy functional specification, but are also easy to manufacture, assemble, diagnose, and maintain. This new approach to design is called concurrent design. We are interested in extending this idea to include environmental considerations. Some of the questions that arise are: How should a product be designed to reduce hazardous wastes? Can ease of recyclability be engineered into a product’s form and materials? What de-commissioning methods should be considered during the design process? How does one evaluate the hazardousness of various products and processes? What are the implications of environmentally motivated design decisions on other aspects of a product? How should the tradeoffs be addressed? These questions point to some important issues that have not traditionally been considered during product design and development, they represent a new area of design that is called Green Engineering.

Green Engineering is the study of, and an approach to, product/process evaluation and design for environmental compatibility that does not compromise product quality or function.

In this framework, a “green” product is both environmentally compatible and commercially profitable.

Technological progress and environmental stewardship are not incompatible goals. Human history is dotted with examples of civilizations that had adopted environmentally conscious lifestyles, while making technological and sociological progress. Since the beginning of the industrial revolution, however, the acceleration of development has overwhelmed the environment. We started experiencing local and global consequences of human-made pollutants. As a result, people decided to take direct control of the problem. This gave birth to the environmental engineering and environmental science disciplines. These approaches, however, have limited themselves to the control and mitigation of a problem, after it has occurred. Green Engineering Design, on the other hand, focuses its attention on the source of the problem.

It has been recognized that environmental issues have implications for engineering design and education (Purcell, 78; Friedlander, 89). There has also been some early work on understanding the relationship between packaging, design and wastes. Only recently, interest has been developing in designing products so that they can be environmentally more compatible (Henstock 88; Navinchandra 90). Henstock’s book reviews current recycling practice for various metal based items. In particular, the book concentrates on steel scrap in automobiles. The study has generated some general principles of designing for recyclability: mechanical disassembly should be simplified, avoid self-contaminating combinations of materials, standardize materials used, and separate high copper content items from steel items. However, highly focussed approaches such as “design for recyclability” may be too narrow and sometimes self defeating (ESD, 91). For example, in automobiles, in order to improve recyclability of plastics it has been suggested that thermoplastics be preferred over thermosets. However, as thermoplastics are not as strong as thermosets, one ends up increasing the bulk of plastics in the car. Though thermoplastics are easy to recycle, they end up generating more emissions to the en-
environment from resin and polymer manufacture. Designing for recyclability alone, hence, may not turn out to be environmentally compatible. It is for reasons such as these that we need to make design choices based on a lifecycle view of a product and the materials involved. It is important that a product’s environmental compatibility not be viewed in isolation. Issues such as cost, reliability, and manufacturability should not be compromised. We argue that all such concerns be evaluated for the entire life of a product. In practice, however, such an analysis is often not done because responsibility for the various areas is distributed. People who are responsible for design, manufacture or use of a product, are often not responsible for its disposal and recovery. This situation exists even within organizations. Consider the following example: there is some special military hardware that is coated and painted with a heavy-metal based chemical. This is done to improve weathering resistance in harsh environments. When the equipment is sent for maintenance and repair, the paints are stripped by sand-blasting and the equipment is re-coated and re-painted. The problem is that the sand used in the blasting gets contaminated and has to be treated as toxic waste!

The cost of disposing off with this toxic waste is not borne by the people who design, manufacture or use the equipment. These expenses are normally not accounted for when the equipment is being purchased. The cost of dealing with the heavy-metal contaminated sand is hidden in the operating costs of the repair and maintenance facility. Life-cycle cost analysis will help us get a better understanding of the true cost of our design decisions. Environmentally incompatible practices result in tangible losses, companies who are quick to recognize and deal with these hidden costs will be more profitable.

1.2 Green Engineering Design

This approach to Green Engineering Design has two parts. The first part deals with the evaluation of designs to assess their environmental compatibility. This is done using a spectrum of indices and measures that we call Green Indicators. The second part of the approach deals with the relationship between design decisions and the green indicators. The aim is to develop an understanding of how design decisions impact a product’s environmental compatibility. This information is used to identify design changes that can improve a product’s environmentability (Blair, 1993; Burke, 1992).

1.2.1 Product Analysis: the Green Indicators

Evaluation of environmental compatibility of a design is based on a life-cycle analysis of the various processes involved from the time materials are extracted from the environment till the time they return to the environment as gaseous emissions, particulate emissions, water borne effluents, or solid waste.

The notion of life-cycle analysis is based on activity models. The various stages that a product goes through from cradle to grave involves activities. We view each activity as a black-box that takes certain inputs and produces outputs. As energy and materials are conserved in each black-box, the outputs of an activity includes products and waste (Fig. 1.1). The decision input is used for activities that can be done in different ways. For example, if the activity is washing re-usable diapers, the decision determines the amount of waste water and heat.

The activity model is the basic building block of life-cycle analysis. Complex processes can be modeled using networks of these activity blocks.

The life of the product starts when materials are taken from the environment. The product finally returns to the environment when it is discarded by the end-user. Along the way, there are many points of pollution. Multiple instances of an icon is used to indicate major sources of a particular pollutant type.
Once the life cycle of product and all its parts has been determined, it is possible for us to calculate a wide variety of indicators:

1. **Percent Recycled.** The percentage of recycled material in a product.

2. **Degradability.** The ratio of the volume of degradable material in a product to the total volume of the product.

3. **Life.** Time it takes for the degradable portion of a product to degrade. A curve showing the expected volume reduction over time is used to determine the life of a discarded item.

4. **Junk value.** This is a measure of the total time a product will take to degrade into the environment. The units are cubic-inch years.

5. **Separability.** A measure of what materials can be separated from a product. It is the ratio of the volume of separable materials to the total volume of the product. The notion of separability is different from disassembly. The aim here is to separate out parts that are made of compatible materials. For example, copper and steel are incompatible in melt, while steel and aluminium may be charged into the same furnace.

6. **Life Cycle Cost.** The total cost incurred in the life of a product. This would include costs of purchasing, maintenance and disposal. This indicator can help surface hidden costs that were not being factored into product costing.

7. **Potential Recyclability.** The ratio of the volume of recyclable materials to that of un-recyclable materials.

8. **Possible Recyclability.** Composites and glued materials are potentially recyclable, but cannot be recycled because they are inseparable. This indicator has to be measured on a part by part basis and available recycling has to take into account the methods and their economic viabilities.

9. **Useful life.** When a material leaves the environment and enters the human world it is being used.

10. **Utilization.** Ratio of the useful life of a material to the time it takes to “return” to the environment. For example, the utilization of a Styrofoam cup is very low because it is used for 5 minutes and takes decades to degrade in the environment.

\[ 	ext{Fig. 1.1 An activity model} \]
11. **Total and Net Emissions.** These indicators take a sum total of solid, gaseous and waterborne emissions from the use of particular materials. For example, paper grocery bags have been compared to polyethylene (HDPE) bags (Franklin, 90). This study compares the net emissions, energy, and water use in the production and recycling of paper and plastic.

12. **Total Hazardous Fugitives.** A measure of the weight of hazardous fugitives from the life-cycle. This is expressed as a ratio of the weight of hazardous chemicals emitted per unit weight of product.

This has been a list of some green indicators that may be used to analyze a given design. The next two subsections present, in some detail, how utilization and separability may be calculated for soda-pop bottles.

1.2.2 **Product Design: using the indicators**

The green indicators may be used to evaluate the environmental compatibility of a part, or to compare various design decisions about feature selection and material choice. In this section techniques that may be used to make specific design decisions are examined. The aim of these techniques is to place environmental concerns side-by-side with other, more traditional concerns such as manufacturing and reliability. The process has three basic steps:

1. Identify green indicators that are undesirably high or low;
2. From the life-cycle, find the source of the problem. In general, one may find one of three sources: production, operation (use by consumer) and disposal/recycling;
3. Finally, product and process decisions at the source of the problem are identified.

Mitigation is attempted by making one or many of the following changes:

1. **Substitution.** The replacing of a particular undesirable feature by another. A tradeoff analysis is made to measure the net impact on the associated green indicators. Fig. 1.2 shows a tool that may be used to assess substitution. The vertical axis shows the value of some green indicator, the horizontal axis shows the value of design parameter that is affected by the substitution being considered.

Consider the following example: in auto design, one might be trying to reduce the weight of the car by substituting plastic for steel. The design parameter is the weight of the car. On the graph, the weight reduces from left to right. The substituting feature is plastic and the substituted feature is steel.

![Fig. 1.2 Net impact analysis](image-url)
As the weight is reduced the amount of plastic increases, hence the life-cycle emissions from plastic increases while that of steel decreases. Further, as more and more steel is substituted in a car, one ends up using disproportionately more plastic. This is because, after a point, one has to start replacing structural parts with plastic; as plastic has lower strength, one needs more plastic to replace a unit volume of steel. The figure shows that there is an optimal level for substitution.

We have found that reducing an automobile’s weight for fuel economy purposes by using plastic can, under certain conditions, be self defeating (Navinchandra, 91). For example: to reduce auto emissions, one might decide to reduce the weight of the car, to reduce the weight one might decide to use plastics; but using plastics increases the total emissions. A balance has to be struck. The tool in Fig. 1.2 plays an important role in finding such balances. Such graphs are prepared for every relevant green indicator. Once the optimal decision is determined separately for each criterion, a multi-attribute analysis (e.g. Pareto chart) has to be drawn to compare the choices.

2. Design for Separability. Parts that are compatible in recycling should be lumped together in easily removable parts. Avoid glues and welds between parts of incompatible materials, prefer snap fits. We should also note that destructive disassembly is a viable option for separation of parts in a discarded item.

3. Form Redesign. The hazardous fugitive indicator may point to finishing operations as a source of problems. For example, if hazardous additives are being used in plastic parts that need a lot of machining and trimming, one might redesign the part or the mold to reduce the need for these finishing operations.

4. Enclosure. Emissions produced during the operation of product may be either enclosed, entrapped or treated. For example catalytic converters are used in cars and special filters are used in copy machines.

5. Design for Recovery. If expensive materials or parts are introduced with the knowledge that the product will be returned for recovery, then one has to make sure that the expensive materials are not too easy to remove (danger from theft), while it is, economically feasible to remove and reuse the material or part.

6. Material Selection. A popular and effective tool for selecting materials are the Ashby charts (Ashby, 89). These charts consider usual material properties such as fracture, Young’s modulus, strength etc. These charts can be extended to handle the green indicators. For example, emissions can be plotted as a function of strength. The aim would be to pick the strongest material for the best strength to emissions ratio. The graph below is a plot of strength vs. relative emissions. On the chart, Al alloys turn out to be the best pick. This is because of the relatively low emissions from aluminium manufacture.

Ashby has 14 other charts that may be used to make tradeoffs between traditional materials science related characteristics such as strength, weight, corrosion, fracture toughness. We are working on extending the list to include the various green indicators.

1.3 Specific Indicators for environmentally compatible design

The results of the recycling projects carried out so far, explain that on the one hand a considerable amount of (manual) work is required for the disassembly of re-usable parts and the segregation of’
material groups and on the other hand high-energy recycling processes have to be applied in some cases. For these reasons, the evaluation of the projects resulted in guidelines relating to “environmentally compatible designs” which allow easy disassembly, applicable for future vehicle generations. They are summarized in Fig. 1.3.

They comprise modifications in joining technology, such as the development of connecting parts which are easy to disassemble and the reduction of components with full-face adhesion, simplification of the draining of service fluids and the central arrangement of electronic components as often as possible. To facilitate the segregation or plastic types during recycling, Mercedes-Benz marks all plastic parts which are heavier than 100 g. In addition the reduction in the variety of materials facilitates the recycling of the disused vehicle.

Fig. 1.4 Shows the variety of plastics which are used in the E-class (mid-range series) of automobiles. Whereas almost 75% of the plastic is comprised of five plastic types (PVC, PUR, ABS, PP and PA), the remaining 25% are divided into ten further types of plastic. Here it seems to be reasonable to reduce the variety of types.

In order to arrive at an economically and ecologically optimum energy and materials balance during production, it is necessary to use the most suitable materials holding them in the cycle as long as

<table>
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<th>PVC</th>
<th>PUR foam</th>
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<th>ABS</th>
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**Fig. 1.3 Guidelines for “environmentally compatible design”**

**Fig. 1.4 Application of plastic in the Mercedes-Benz Executive-class**
possible by the use of appropriate recycling methods. This leads to a holistic consideration: i.e. balancing and evaluating the consumption of energy and raw materials, the benefit, recyclability and environmental compatibility.

The complex way of drawing up an ecological balance, which may be accompanied by numerous insecurities, imponderabilities and subjective assessments is shown in Fig. 1.5.

When drawing up such a balance the recycling is not free of cost. Similar to the production process, it requires energy and auxiliary material and causes emissions and residues. For this reason it does not make sense to go for recycling at all costs; rather, the installed recycling systems need to work at minimum losses (cost-wise).

1.4 Life Cycle Analysis

1.4.1 General features

In order to develop new technologies, modify existing ones, or redesign products to meet the new environmental criteria, Life Cycle Analysis (LCA) or ‘Cradle to Grave Analysis’ of the technology has to be performed. In today’s rush by industry to make changes in product design that would enable their products to meet requirements for their ultimate disposability or recyclability, LCA assumes great importance. With a growing recognition that the production and consumption of manufactured products has an effect on resources and the environment, the design of products with consideration for the final state or use of the product is essential Fig. 1.6 shows a typical Life Cycle structure.

A complete Life Cycle Analysis consists of an environmental audit of five major sections:
1. Raw Materials Acquisition
2. Product Manufacturing/Packaging Manufacturing
3. Consumer Use
4. Recycle, Compost
5. Final Disposal.

Where each of these five steps is comprised of many microprocesses to be analyzed for material and energy flows, as in Fig. 1.7 (Benda, Noragen and Sticklen, 1993).

LCAs are important for the product design process. The current trend towards quality of design has led towards design for manufacturability (DFM: Design for Manufacturability) and assemblibility (DFA: Design for Assemblibility). As environmental regulations become more stringent, manu-

![Fig. 1.5 Steps for the life cycle assessment](image-url)
facturers are also confronted with the task of product-design considering the ensuing waste manage-
ment options (DFR&C: Design for Recyclability and Compostability). Life Cycle Analyses (LCAs)
assume great importance for this design process. LCAs provide ‘cradle to grave’ environmental in-
formation for decision making by consumers, manufacturers, and governments. This information sig-
ificantly affects the ability to maximize source reduction, re-use, recyclability, and recycled content.
A tool such as LCA can aid in diminishing the impact a product has on the environment and work to-
ward a partial solution of our nations’ (worlds’) growing waste management problem. Thus far, the
application of Life Cycle Analysis has varied from product comparison to process development and
improvement. The results from these analyses differ due to problems associated with LCAs, such as
data limitation and boundary definitions. An appropriate LCA standard is being developed which can
address these issues objectively.

The generation of a Life Cycle Analysis requires the knowledge of thousands of various process-
es. But with this vast knowledge, product design engineers can incorporate composting, recycling, or
other waste management solutions directly into the original design and interactively acquire the en-
suing environmental impacts from such a system. The knowledge rich domain and general structure
of LCAs leads towards the use of an Expert System. An Expert System can be applied to overcome
some of the current difficulties with LCAs and provide possibilities for further LCA potential.

Several problems have limited wide acceptance of Life Cycle Analyses. Some of these major
problems are 1) Data Limitation, 2) Assumptions, 3) Lack of a Standard, 4) Cost, 5) Lack of a Com-
mon Currency, 6) Boundary Definitions, 7) Weighting Factors, and 8) Data Aggregation.

![Fig. 1.6 Typical Life Cycle Analysis Structure](image1)

![Fig. 1.7 Micro-Analysis](image2)
1) **Data Limitation.** Data are not always available as in the case where manufacturers have proprietary equipment or processes. This information is essential for the most correct and up-to-date LCAs. The lack of manufacturers’ input has been a major problem for current LCAs due to the manufacturers’ fear of divulging proprietary information.

The solution to this problem may be approached in one of two ways (or both). Governments (EPA, Standards Associations, etc.) could require disclosure of relevant information or make it economically beneficial to provide information to be used solely for the construction of the data bases required to run an LCA. Second, perhaps in combination with the first, is that proprietary information could remain locked/hidden in the appropriate data base, where the providing manufacturers are not at risk. This lack of information availability, however, remains a major stumbling block for most analyses. The EPA is making strides towards an accessible database, which is needed to increase the applicability of LCAs (Baumgartner and Rubrik, 1992).

2) **Assumptions.** Another problem in this domain is the representation of the allowable assumptions. For some processes, the quantitative data is known and attainable while for others a best guess is as far as can be done. It is often easy to assume a case out of reality, which could make an assessment no longer useful. Generally, these oversimplifying assumptions have plagued LCAs in the past, since there are many external forces acting on a products life cycle. This can be overcome by an extensive knowledge base on the processes themselves and the components involved. With this information, a product manufacturer can interactively ‘see’ the impact a design will have on the environment and can interactively judge whether assumptions are necessary or viable.

3) **Lack of a Standard.** One of the greatest difficulties is the lack of a standard for LCAs. Marketing people have used this fact to their advantage, claiming ‘green’ superiority over other products in the same class, only to be rebuffed by another LCA determining completely opposite results. In this sense, LCAs can currently be manipulated for any purpose. Some feel this to be a benefit for LCAs, but it merely serves to injure the integrity of such studies.

Not only does this render LCAs untrustworthy, but it also points out that without a standard, LCAs are just another marketing weapon. An example of opposing results of studies considering the life cycle of both single-use and reusable diapers shows how the analyses of the same products can differ.

4) **Cost.** The work-hours required to carry out an LCA currently costs time and money. This cost has made LCAs unattractive to some.

5) **Lack of a Common Currency.** According to Norman Dean, there exists no common unit for comparing different environmental impacts. He claims that it is difficult, for example, to compare the impacts of a ton of carbon dioxide with a ton of benzene, much less compare the loss of an endangered species with human exposure to a carcinogen. But the purpose of an LCA is not to compare, but to present. With the overall impact information provided by an LCA, decisions can be made to minimize environmental burden.

6) **Boundary Definitions.** Altering the boundary of a problem will consequently change the results. The study may still be termed an LCA (there is no standard), but may omit certain steps which dramatically affect the outcome.

7) **Weighting Factors.** A very large problem also exists in weighting factors from other media using LCA. For example, should ozone-depleting chemical release be weighted against global-warming-contributing-gases release?
8) Data Aggregation. Both ecological and environmental assessment instruments have to deal with the problem of aggregation, that is, the reduction of the potentially large number of impacts to a number that is manageable by decision-makers.

In the near future, an LCA audit will be required for every product and process, if not due to government regulation then due to the markets (consumers) demand. Life Cycle Analyses can provide essential information necessary to improve each product and process environmentally and economically. However, it should not be used to compare the environmental merits or demerits of competing products, but to present information regarding the impacts of the individual products. The characteristics of Hierarchical Classification an Expert System, can be exploited to provide a tool to aid such analyses.

1.4.2 Hierarchical classification

One of the first tasks in conducting an LCA is to gather and organize the possible process steps involved in producing the to-be-designed new product. Because there are numerous possibilities for each facet of design selection, each with environmental impact, the amount of knowledge which needs to be organized in intelligible (to humans) structure is quite large. Knowledge-based Systems (KBS) (more commonly known as expert systems) have been developed over the last several decades as a means to address the organization and utilization of large amounts of information. Typically, along with a representational backbone for storing organized information, KBS approaches are endowed with inference techniques to traverse the knowledge structures in an efficient and effective manner. Our major use of KBS in the current study has been primarily limited to selecting an appropriate knowledge structure for representing knowledge about product lifecycles. The KBS technique applied to represent product lifecycle information has been Hierarchical Classification (HC). HC is one of the so-called “task specific architecture” approaches to KBS, a full discussion of which is beyond the scope of this work.

A Life Cycle analysis (LCA) can be broken into a specialization hierarchy. This hierarchy consists of the processes involved in the five major sections in a life cycle. In HC, categories are organized such that children (the connected nodes at the next level down the hierarchy) represent a subcategory, and the parent (the connected node one level up the hierarchy) represents a super-category of the current node (Fig. 1.8 illustrates an abbreviated and simplified hierarchy for a products life cycle).

HC is a representational and problem solving technique that can efficiently compare a set of pre-enumerated categories with a given case of interest to find those categories that best describe the cur-

![Fig. 1.8 Example of a classification scheme for a products life cycle analysis.](image-url)
rent case. A prototypical use of the HC approach (and historically the first use) was to support diagnostic problem solving in the medical area. As part of the conceptual LCA process, hierarchical classification can be used as a structure to organize LCA knowledge. Reiterating one of the most serious difficulties with developing LCAs is the vast number of possible considerations which are necessary to develop an appropriate LCA for a given situation. As an automated problem solver, a hierarchical classifier can help reduce the number of paths one must investigate along which information gathering must be accomplished. And as an “intelligent textbook” for representing LCA knowledge, an HC representation can be an effective means of storing LCA information in such a manner that specific information can be easily found. As an example of how HC can be used to represent knowledge necessary for LCA construction, consider Fig. 1.8. In Fig. 1.8, a generic product (GenProduct) can be made up of five (any number, say, cap, bottle, label etc.) separate components, A, B, C, D, and an associated (usually) packaging. Each one of these components has children nodes for processes: RM (Raw Materials) Acquisition, Manufacturing, Operation, Recycling, Disposal (Only component B is expanded in Fig. 1.8 for the sake of clarity).

Some of these first generation nodes will also have children: e.g. the Recycling node has both Compost and Recycle as children. These categories become more specific as the hierarchy. These categories become more specific as the hierarchy is traversed from the top towards the lower, more specific nodes. Strictly speaking, the knowledge organization in Fig. 3 is not a specialization hierarchy as would normally be developed following the HC approach since each node is not necessarily a specialization of its parent node. However, the goal of using the organization shown in Fig. 1.8, is to identify the applicable terms for analysis for performing an LCA in a given industrial situation. Such top level use of an HC structure is consistent with normal practice for HC applications.

In Fig. 1.8, each node in the hierarchy is responsible for determining the process steps involved for its category relating to the current problem. For example, the RM Acquisition node in Fig. 1.8 is responsible for determining the processes involved for acquiring raw materials for manufacture of component B of GenProduct. Each process node will likewise be queried for information about environmental impacts. Each of these subprocesses or Flows have their own impacts which are imbedded in their respective filter. Such as Transportation and Energy, as shown in Fig. 1.9.

Each node can be thought of as a specialist in the field which the node represents. Higher level nodes act as managers to the lower-level specialists. Not all nodes, however, are relevant to all components. In the Processing, Reaction Injection Molding (RIM), for instance, may be important for plastics, but will not be needed for cotton products. The general idea is that each node requires a list of features that are important in determining whether the category it represents is relevant to the present system or not, and a list of patterns that map combinations of features to confidence values. This essentially classifies the product with each node. For a given product, confidence values will depend on the physical properties of the product, the technologies normally used and other practical considerations. The output value will be a numerical value within some specified interval, for example, 3 to 3. Positive values would indicate confidence in the categories’ applicability while values less than or equal to zero indicate a low level of confidence.

![Fig. 1.9 Transportation and Energy Filter](image)
Consider the Manufacturing node in Fig. 1.8. As previously noted, this node determines the process steps for product B for its manufacturing process. Each node includes a list of patterns that map to some confidence value. At the deepest level of the hierarchy, specific confidence values are chosen and sent back up the hierarchy for the department’s manager to report to the top node.

Before a manager sends the exploration down to its specialists it will use a technique called “establish-refine”. A node will establish by applying its local pattern-match knowledge to determine that the confidence value is ‘good-enough’. That is, in dealing with plastics, one can be fairly confident of the use of a RIM machine, so a confidence value is given of 2. Once established, a node will attempt to refine itself by asking its more detailed sub-categories (its direct children) to establish themselves. If later a match is found to conflict with the value of 2, that value will then be removed by the ‘advice’ of the specialists. In this way ‘the most detailed categorical description can be determined.

Fig. 1.10 Automotive Life-Cycle Impacts
(In the HC used for this research, a value of 2 or greater Establishes, 1 or zero Suspends, any minus value is Rejected). This type of pruning is a large advantage gained by the establish-refine technique. This prevents the system from wasting time. Whether or not a given node will establish depends upon the pattern-match knowledge encoded in the node. A category that rules out or rejects with a low degree of confidence does not ask its daughter nodes to establish, thus pruning the search space or cutting down the search required. In order to solve tough problems efficiently it is important to eliminate some of the details of the problem until a solution that addresses the main issues is found. Then an attempt can be made to fill in the appropriate details.

1.4.3 The application of LCA to the automotive sector

There are currently over 550 million motor vehicles on the road. One third of these are in the United States (Spoel, 1990). A high percentage of the steel (80%) and aluminium (70%) in the 10 million automobiles that are discarded each year is recycled, so substitution of polymer composites for steel could have significant and far reaching impacts on the environment. Polymer composites are extremely difficult to recycle for technical and/or cost-effective reasons. Combustion of the waste with recovery of the energy value is possible, but problems with non-combustion of reinforcing or filler materials and the control of particulate and toxic emissions and corrosive substances make this option cost-ineffective. The decreasing availability of landfill space has dramatically increased the cost of this alternative.

Fig. 1.10 shows the environmental impacts of automobiles throughout their lifecycles. First, large amounts of energy are consumed in the extraction and processing of the raw materials needed to produce iron, steel, plastics, and non-ferrous metals. Water is also consumed while emissions and solid wastes are generated. The manufacturing processes for forming the raw materials and assemble the components also use energy and water, and generate emissions and solid wastes (Thurston, 1994).

During its useful life, the automobile consumes energy in the form of gasoline, and generates emissions. It will most-likely undergo repairs and may receive new or used replacement parts. The average useful life of an automobile is 12.6 years (Mascarin and Dieffenbach, 1992).

At the end of their useful lives, 90 percent of vehicles undergo some degree of recycling (Spoel, 1990). Some components are reused, some materials recycled, and the remainder is landfill filled. First, a wrecker/dismantler strips the vehicle of usable parts. The sale of used parts is the largest source of income for the wrecker/dismantler, representing 75.3% of total income, relative to 4.3% for the sale of scrap metals (Ness, 1984). Next, parts that can be more efficiently recycled separately are removed, including the radiator, battery, automatic transmission, and catalytic converters. Parts that are unacceptable for the shredder are also removed, including the radiator, battery, automatic transmission, and catalytic converters. Parts that are unacceptable for the shredder are also removed, including gas tanks, tires, and seats.

The stripped hulk is then sold to a specialist who compresses it to a 10 inch height for transport to a shredder operator. The shredder uses large hammermills to further reduce the hulk to fist-sized pieces. Shredders typically operate on 80% to 90% automobile feed (Ness, 1984), the remainder being refrigerators and similar appliances containing a significant amount of ferrous metals. The shredded material is magnetically separated to remove the ferrous portion. The non-ferrous fragments contain 70% metals, 30% of which is aluminium (Tribendis, et al., 1984).

This portion is then separated by means of water and/or heavy media separators, ferrofluids, cyclones, pyrolysis, sweating, eddy-currents, or hand-picking. The recoverable materials include ferrous metals, copper, zinc, and aluminium which are sold to secondary metal producers. In addition to recoverable metal, a significant amount of nonmetallic debris is left after the shredding process. This automobile shredder residue (ASR) “fluff” includes glass, dirt, plastics, rubber, and fabric. Although the ASR contains recyclable materials such as glass and plastics, it is currently landfilled since it is not economically feasible to separate it into recyclable components. A typical modern car contains 260 to 280 lbs of plastic in 20 different forms (Misner, 1991). ASR has a very high ash content (50%) and produces corrosive and polluting fumes (Henstock, 1988).
1.4.4 Concurrent multiattribute evaluation

Thurston, Carnahan and Liu, (1991) have developed an Evaluation Driven Design Analysis (EDDA) methodology which directly incorporates multiple attributes into the design decision-making process. The main concept is that the design process should be driven from beginning to end by how the design artifact will be evaluated as a bundle of incommensurate attributes. This approach provides a rigorous, analytically sound procedure for guiding the design process, based on multiattribute utility theory and optimization theory.

The environmental compatibility of a product must be viewed as an important aspect of the design process. “Design for environmentability” sometimes leads to the lowest cost design, but unavoidable tradeoffs must often be made between environmental impact, cost, customer satisfaction, reliability, manufacturability and other attributes. In addition, tradeoffs between environmental impacts that occur at different phases of the lifecycle might be necessary. This approach is to perform concurrent multiattribute design evaluation early in the design phase to simultaneously consider all conflicting and nonconflicting attributes. The end result is the determination of the overall value of each design alternative. Several methods are available for dealing with these tradeoff issues, including weighted sum methods, multiattribute utility analysis (Thurston, 1991), fuzzy set analysis, and the analytic hierarchy process (Saaty, 1980). These methods offer varying degrees of ease-of-use and sophistication, but each method helps the designer deal with conflicting attributes by separately defining multiple attributes (or characteristics of a design) and addressing their relative importance or the willingness of the decision-maker to make tradeoffs between them.

For this illustrative problem, the Analytic Hierarchy Process (AHP) is used to perform the concurrent multiattribute design evaluation. The goal hierarchy is shown in Fig. 1.11, Table 1 shows estimates of the total of each materials’ impact at each level in the goal hierarchy throughout the lifecycle.

Environment. Production of energy, use and post-use are considered. Production Energy - One-fifth of the U.S. energy budget is spent on raw materials production (Ness, 1984). Table 1 shows production energy required for each material (Niemczewski, 1984) (Farrissey, 1991). The values for RRIM and SMC include their glass contents. Material production that is more energy intensive, such as the production of aluminium, also tends to generate more emissions and consume more water. For this reason, production energy will be used as the overall measure of environmental effect in the production phase.

![Fig. 1.11 Goal Hierarchy for Automotive Material Selection](image-url)
Use - Transportation in 1981 accounted for 25% of the total U.S. energy consumption and 50% of the U.S. petroleum usage (Niemczewski, 1984). A car with better gas mileage will consume less fuel over its lifetime and, subsequently, release fewer emissions. Two material properties, weight reduction and design flexibility, can have a significant effect on the gas mileage. High design flexibility allows more aerodynamic designs to be achieved. It is estimated that 6.7 liters of gasoline is saved for every kilogram of weight reduction (Farrissey, 1991).

Post-use - The values in table 1.1 for post-use value refer to the monetary value (or liability) of the vehicle after its useful life. Steel and aluminium show positive values because they will be recovered during recycling. SMC and RRIM show negative values which reflect their contribution to the cost of landfilling the “fluff” generated during the shredding process. Tipping fees average $50 to $60 per ton in the Northeast with a few locations charging $100 per ton (Kiser, 1991).

Manufacturing Cost. Fixed and variable costs were assessed through the application of Technical Cost Modeling (Mascarin and Dieffenbach, 1992). The model is derived from regression analysis of case study data. Variable costs shown are for an annual production volume of 100,000.

Table 1.1 Material Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Stamped Steel</th>
<th>Stamped Aluminium</th>
<th>SMC</th>
<th>RRIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Energy</td>
<td>260</td>
<td>384</td>
<td>362</td>
<td>311</td>
</tr>
<tr>
<td>(MJ/fender)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Efficiency</td>
<td>0</td>
<td>16.6</td>
<td>6.5</td>
<td>12</td>
</tr>
<tr>
<td>(liters saved/fender)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Use Value</td>
<td>$0.06</td>
<td>$0.42</td>
<td>($0.06)</td>
<td>($0.05)</td>
</tr>
<tr>
<td>(per fender)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Fixed Cost</td>
<td>$9.01</td>
<td>$8.99</td>
<td>$6.98</td>
<td>$6.88</td>
</tr>
<tr>
<td>(per fender)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Variable Cost</td>
<td>$5.03</td>
<td>$10.79</td>
<td>$8.16</td>
<td>$7.60</td>
</tr>
<tr>
<td>(per fender)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modulus (psi • 10^6)</td>
<td>30</td>
<td>10</td>
<td>1</td>
<td>0.32</td>
</tr>
<tr>
<td>Yield Strength (ksi)</td>
<td>100</td>
<td>25</td>
<td>10.6</td>
<td>3.1</td>
</tr>
<tr>
<td>Weight Savings (% over steel)</td>
<td>0</td>
<td>49.6</td>
<td>19.3</td>
<td>35.7</td>
</tr>
<tr>
<td>Corrosion Resist.</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>(1=worst 5=best)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Flexibility</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>(1=worst 5=best)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dent Resistance</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>(1=worst 5=best)</td>
<td></td>
<td></td>
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</tbody>
</table>
1.5 Life Cycle Engineering

1.5.1 The decision support methodology

The Life Cycle Engineering approach as developed at PE Product Engineering Ltd. aims at including all relevant information from the dimensions of technology, economy and environment in a single decision supporting management tool. All relevant information must be available within the design phase of products or systems as soon as possible, in order to arrive at best informed decisions. Basis for all decisions should be information bases on the whole life cycle of a product. The consideration of all life cycle stages is strongly recommended to avoid tradeoffs.

This approach therefore makes use of the Life Cycle Costing theory (LCC) to describe the economical parameters of a product. The Life Cycle Assessment methodology (LCA) as defined in the ISO 14040 series is being used to describe the environmental interactions of the product, parallel to the economical considerations. Finally Quality Function Deployment (QFD) and Total Quality management (TQM) tools are being used to describe the technical parameters of the system and to ensure the accordance with the related requirements.

Fig. 1.12 shows the overall Life Cycle Engineering approach, which consist of the three main subsets Life Cycle Cost, Life Cycle Assessment and Total Quality Management.

This approach is aimed at defining a decision basis or management tool in the automotive industry to be used in the car design phase to support decisions like material selection, process choice and product optimization. This includes the description of material profiles, manufacturing and process simulation, the simulation of the usage phase and the description of the end-of-life treatment. Together with the system partners, the suppliers and material producers, a huge database is under development (Saur et al., 1997).

The whole approach is designed as an iterative procedure. In the beginning a fundamental database is generated, describing materials and processes. This information is being used in the daily de-
sign work. Within this process data is always refined and updated. Decisions derived from today’s knowledge are later crosschecked and reviewed. This procedure allows to update the database and ensures that up-to-date knowledge is being used.

Life Cycle consideration in the automotive industry are mainly based on the consideration of single parts, which can be looked upon as being representative for a larger number of parts. The representative examples are chosen with respect to material and processing technology, including information like geometry etc. This then is the basis to derive generic information for automotive parts in general. This approach seems to be the only way to describe complex systems like complete automobiles. This approach has proved its value in several projects.

The consideration of the complete life cycle of a product or systems ensures the avoidance of tradeoffs. This view on the whole life cycle is often different from today’s consideration of the automobile producers, which often only consider the production phase especially in the economical dimension. Opposite to these management tools the Life Cycle Engineering approach aims at including the complete lifespan of a product.

The Life Cycle Engineering approach aims at helping designers to arrive at best available information is being required to make decisions as soon as possible. The earlier designers can identify which designs can be neglected, the lesser the expenditures are in total. So not only expenditures can be saved. In the same way the design process can be shortened in time. This is getting more and more important with the product innovation times are decreasing rapidly. Therefore designers need rules which they can use. In the following one rule is demonstrated exemplary.

It is well understood that production and use of automobile parts contribute differently to several environmental problems. Special meaning has been attached to the achievable weight savings between different design options. Weight is very much related to fuel savings in the use phase. An often raised question is how large the weight savings have to in order to arrive at overall environmental benefits. The main problem often is that lightweight materials contribute to different environmental problems in a different manner than the traditionally used materials. In the same way the cost situation differs quite significantly. Fig. 1.13 shows the relation between two different materials with respect to their relative contribution to the global warming problem as a function of the achievable weight savings.

![Fig. 1.13 Decision support for designers](image-url)
The function of the relative contribution to the environmental problem global warming as a function of weight savings is shown with the confidence levels arising from the error calculation of the Life Cycle Assessment. These confidence levels must have significant influence in the decision. This has special meaning in the design phase where all information on the parts or systems themselves have to be looked upon as not yet stable, because the design is not yet finalized and therefore the information on weight and processing have to be used carefully.

The economical trade-off barriers and the technical feasibility level are included as well in order to demonstrate the overall significance of the decision. The Life Cycle Engineering methodology consist of different tools which are used in parallel in order to give best possible decision support in the R+D phase.

1.5.2 The material selection for a body-in-white

In this section the assessment of different design for a “body in white” are discussed exemplarily. The LCA of the different car body designs contain the following steps: Basis of all considerations is a suitable definition of the goal, scope and the description of the precise boundary conditions. With this in consideration the next step inventory is performed. The inventory step is aiming at collecting and calculation all necessary information.

The material selection for a car body in the automotive sector obtains great importance when resource and energy obtains great importance when resource and energy consumption are taken into consideration. Steel, today with the widespread application for car bodies in the automotive industry seems to be limited in the lightweight design. Therefore this investigation shows a comparison of car bodies out of different materials (steel, high strength steel and aluminium) for a premium class car. In the case of the aluminium body two different scenarios are discussed. On the one hand the aluminium import mix, an averaged aluminium sold on the German market, and on the other hand aluminium produced according to the best available technology (BAT). The aim was to identify the possibilities and limits of the four car body designs over the whole life cycle. The technical requirements of all designs are identical; this ensures that the functional unit is well defined and consequently comparable. In the following, the main parameters of a middle class car with a “body in white” out of steel are discussed, Table 1.2. The technical values of this “body in white” are reference values for all other car bodies considered in this context.

<table>
<thead>
<tr>
<th>Total weight</th>
<th>Body weight</th>
<th>Running distance</th>
<th>Fuel consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800 kg</td>
<td>400 kg</td>
<td>250.000 km</td>
<td>14 l/100 km</td>
</tr>
</tbody>
</table>

Fig. 1.14 shows the materials and weight reduction potentials of the different car body designs. Basis for this investigation was the car production situation in Germany 1995. All data and information are industry average (1993-1995). The life cycle of the car body starts with the production and distribution of the raw materials. In the same way, all the necessary process steps for the production of materials and the different “body in white” designs are considered. This includes all transport steps as well as country or plant specific energy supply. The LCA also includes the utilization phase for the different car body systems. The fuel reduction rule that is applied to this investigation was the 5% - rule. That means a 5% fuel reduction to 100 km in the case of a 10% weight reduction from the total car. The recycling loop after the utilization phase is not included in this investigation due to the fact that the influence of recycling is not dominant for this consideration.
The following common system boundaries are the basis for this investigation:

• The LCA covers the mining and the synthesis to the raw material and all further steps directly related to the process route till to the “body in white”.

• The used energy is linked back to the single energy carrier. In this case the consideration take place at the mining of the energy carrier and end at the conversation to the input energy (including distribution losses) to the specific process.

• The production and disposal of plants, machines and transportation means are not taken into consideration.

• All transport steps are included in the investigation.

• Secondary effects like adapted aggregates, traveling gear etc. are considered in the utilization phase. In the following table 1.3 the total car weight reduction is demonstrated, when additional 35% secondary weight savings are included.

Table 1.3 Total car weight reduction with additional 35% secondary effects for steel and aluminium.

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>New steel design</th>
<th>Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total car weight [kg]</td>
<td>1800</td>
<td>1665</td>
<td>1584</td>
</tr>
<tr>
<td>Weight reduction [kg]</td>
<td>-</td>
<td>135</td>
<td>216</td>
</tr>
<tr>
<td>in [æ]</td>
<td>-</td>
<td>7,5</td>
<td>12,0</td>
</tr>
</tbody>
</table>

Fig. 1.14 Material and weight of the different car body designs
In the following Table 1.4 the specific system boundaries for the different car bodies are shown.

Table 1.4 Car body specific system boundaries.

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>New steel Design</th>
<th>Aluminium Import Mix</th>
<th>Aluminium (BAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw material production</strong></td>
<td>Industry data from Europe considered supplier specific 1994</td>
<td>Industry data from Europe considered supplier specific 1994</td>
<td>Primary Aluminium Import Mix</td>
<td>Primary Aluminium (BAT)</td>
</tr>
<tr>
<td></td>
<td>Further production in Germany 1994</td>
<td>Exploration neglected explosives neglected</td>
<td>Further production in Germany 1994</td>
<td>Exploration neglected explosives neglected</td>
</tr>
<tr>
<td></td>
<td>Waterborne emissions form ore and coal mining not considered</td>
<td>Waterborne emissions form ore and coal mining not considered</td>
<td>Alloving elements as titanium etc. are considered</td>
<td></td>
</tr>
<tr>
<td><strong>Material production</strong></td>
<td>Hard coal and coke production considered supplier specific (1994)</td>
<td>Hard coal and coke production considered supplier specific (1994)</td>
<td>Mining of bauxite in Australia</td>
<td>Mining of bauxite in Australia</td>
</tr>
<tr>
<td></td>
<td>complete steel works inclusive milling and galvanizing balanced for suppliers (1994)</td>
<td>complete steel works inclusive milling and galvanizing balanced for suppliers (1994)</td>
<td>Alumina production also in Australia; with a mix out of 20% heavy fuel oil, 70% light fuel oil and 10% natural gas as fuel for the calcination</td>
<td>Alumina production with natural gas as fuel for the alumina calcination</td>
</tr>
<tr>
<td></td>
<td>zinc production considered (1993)</td>
<td>zinc production considered (1993)</td>
<td>Electrolysis (incl. country-specific energy supply) balanced side specific for the primary aluminium Import Mix 1994</td>
<td>Electrolysis (energy supply from water power) balanced side specific for all suppliers (1994)</td>
</tr>
<tr>
<td><strong>Processing</strong></td>
<td>press shop German average</td>
<td>press shop German average</td>
<td>press shop German average</td>
<td>press shop German average</td>
</tr>
<tr>
<td></td>
<td>punching residues 100% recycling</td>
<td>punching residues 100% recycling</td>
<td>punching residues 100% recycling</td>
<td>punching residues 100% recycling</td>
</tr>
<tr>
<td><strong>Energy supply</strong></td>
<td>supplier specific; country grid mix or plant specific</td>
<td>supplier specific; country grid mix or plant specific</td>
<td>supplier specific; country grid mix or plant specific</td>
<td>supplier specific; country grid mix or plant specific</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td>supplier specific</td>
<td>supplier specific</td>
<td>supplier specific</td>
<td>supplier specific</td>
</tr>
<tr>
<td><strong>Data quality</strong></td>
<td>supplier specific (1994) and partially literature</td>
<td>supplier specific (1994) and partially literature</td>
<td>supplier specific (1994)</td>
<td>supplier specific (1994)</td>
</tr>
<tr>
<td></td>
<td>very good</td>
<td>good</td>
<td>very good</td>
<td>very good</td>
</tr>
</tbody>
</table>
1.5.3 Results from the impact assessment

The Impact Assessment of the Life Cycle Assessment is a broadly and controversially discussed topic. In the past impact assessment methods were developed in order to help deriving information from the inventory in order to inform decision making. Due to the fact that volume and content of the Life Cycle Inventories grew significantly with the time, it became more and more difficult to draw conclusion directly. So impact assessment was invented. Different methodologies were published, SETAC founded working groups on this item in North America and Europe. Today Impact Assessment is a research topic.

With the time people began to understand the impact assessment idea covers more than only the concentration of information coming from the inventory. The more people started working with impact assessment the more the added value of this methodology came to the surface. Today it is broadly accepted, that impact assessment is the only interface of LCA with the environment. Dealing with the potential effects and impacts of the interventions identified in the inventory, the impact assessment offers a great opportunity to enlarge the conclusions which can be drawn from the whole LCA and give it a real iterative nature by setting requirements and give help which data has to be collected due to is relevancy for the environment.

The Life Cycle Impact Assessment is aiming at translating the findings from the inventory in a so-called impact profile, which consists of 10 to 12 different environmental themes like global warming, ozone depletion and acidification, amongst others. Based on this profile a better understandable and more reliable result from the following valuation procedure can be achieved. This concentration of information is also aiming at making the large volume inventory information more easily handable and more understandable.

For this purpose the inventory parameters are connected with their related environmental problems they contribute to. The environmental themes are aiming at three main protection targets (safeguard, subjects): human health, environmental impacts. Moreover potential impacts on human health and ecosystem stability are subject of the considerations.

The individual impact categories have different foundations. They differ with respect to their individual scientific background and basis and the respective content to more or less subjective choices in the single impact models. Therefore the impact assessment results must not be used for e.g., regulatory actions or global trade issues.

Moreover the impact assessment is aiming at identifying important contributions to environmental problems and resource intensity of a product along is whole life cycle in order to help finding improvement options. The impact assessment therefor assist in comparing alternatives and process or material options. Moreover the impact assessment also shows interfaces to the use of other EMS tools.

Within the framework of LCA the iterative nature of the whole procedure has to be pointed out. Within this context inventory information as such is not useful without the impact assessment. This means that in the other way round the impact assessment has to set requirements for the inventory, which data has to be collected.

Within the step Classification the individual inventory parameters or sorted with respect to their contribution to the single impact categories as chosen in the goal and scope definition. In order to avoid double counting a differentiation can be made between parallel and serial effects in the cause-effect chain.

Within the Characterization the inventory parameters are modeled according to their relevance within the individual impact category. The models used follow the equivalence impact category. The models used follow the equivalence impact principle of the potential impact of the individual parameters or substances. This step is an aggregation. The choice of the used models has to be stated and documented.

The valuation step within the impact assessment is aiming at prioritizing and weighing impact categories among each other. This step is not scientific defendable and necessarily contains individual
or company specific preferences and values. Today on the international level no common agreed upon method is available. So companies have to set up their own valuation procedure. Nevertheless the valuation is a necessary step within the whole framework. The international standardization is expected to follow the principle to standardize general principles and the framework by e.g. setting minimum requirements and making documentation of the choices and selections obvious.

Opposite to the evaluation step within the Interpretation, which takes inventory and impact results into consideration in order to prepare on overall judgement from the LCA study, the valuation within the impact assessment is only aiming at a comparison of the different impact categories amongst each other (Fig. 1.15).

Fig. 1.15 Outline of Impact Assessment
Chapter 2
The end-of-life vehicle (ELV) disposal route

2.1 The current end-of-life vehicle disposal route

2.1.1. General procedures

Environmental issues are an increasingly important factor to society. For the car industry this has high-lighted issues such as fuel consumption, air pollution, factory emissions and of late the disposal of end-of-life vehicles (ELVs). Historically, disposal has resulted in about 75 per cent by weight of each vehicle being recovered for recycling. This has, however, been limited to the high-value components suitable for reuse or resale and to the metallic content of the vehicle. The remainder of the vehicle has usually been disposed in landfill. Landfilled material is thus a mixture of glass, road dirt, mixed types of rubber, a variety of different plastics in various forms, for example solid, foamed, painted, etc., as well as oil and other vehicle fluids. No one has so far been able to economically separate the intimate mixture of these materials in shredder residue to allow successful materials recycling to take place.

Currently a typical disposal route for end-of-life vehicles is as indicated in Fig. 2.1. The ELV is taken to a vehicle dismantler, who removes such components and assemblies as may be profitable. There is some debate surrounding the proportion of vehicles that receive the attentions of a vehicle dismantler on their way to final disposal. Many in the industry would suggest that nearer 80 per cent of vehicles pass through a dismantler prior to entering the scrap metal recovery chain. The blurred boundary between dismantler and scrap operator may be a factor in this uncertainty.

Parts removed by a dismantler are defined by market demand and will generally include items such as engine, gearbox and other mechanical parts, electrical and electronic components, and of course part-worn tyres. Other componentry, typically body shell, trim, seats and other fittings, are less likely to be dismantled because there is far less demand for them. Current estimates suggest that there are around 2000 dismantling operations in the United Kingdom (Shergold, 1994).

From the dismantler, the ELV will pass into the scrap metal industry. In the United Kingdom this comprises around 5000 businesses, around 2000 of these being scrapyards. At the smaller end are the scrap collection operations, often itinerant and equipped with nothing more than transport. Only a very small proportion of the total of end-of-life motor vehicles pass through these businesses, which tend to specialize in light iron categories collected from domestic premises.

The next level up in the scrap industry is the small yard which may be equipped with a press and shear machine and a baler. As indicated in Fig. 2.1, around 25 per cent of the complete ELVs arising will pass through this type of business en route to the shredder. Scrapyards of this type may well remove valuable non-ferrous metal such as brass or aluminium radiators, copperbearing componentry such as motors, generators, etc., and batteries. Their main contribution to the ELV process will be to pass the vehicle hulk through a press and shear machine, improving transport economics. This plant, as the name suggests, compresses and crops the remains of the vehicle, allowing around 20 to 30 vehicles to be transported per 20 tonne load, rather than the four or five that could be carried while the ELV is in a complete and unprocessed state. Most ELVs arrive at the shredder businesses as pressed and sheared material, or as flattened vehicles, usually from dismantlers.

Shredders or fragmentizers are large, capital intensive, powerful hammer mills, usually of about 1000-2000 h.p., and in the size range are capable of reducing cars and light commercial vehicles to
fist size pieces at the rate of around 100 units per hour. The output material from the shredder is subject to magnetic separation and air aspiration techniques, which enable segregation into ferrous metallic, a light fraction that is predominantly non-metallic and a heavy fraction. The latter is a mixture of non-ferrous metallic and non-metallic materials. The heavy fraction is the either hand-sorted or passed through a variety of automated processes to isolate materials such as copper, brass, zinc, magnesium, aluminium and non-magnetic stainless steels. The non-metallic part of the heavy fraction, which is known as automotive shredder residue (ASR) and comprises an intimate mixture of road dirt, plastics, rubber, vehicle fluids, glass, etc., is then conventionally landfilled. There are over 30 shredders site in the United Kingdom, although, due to the recession, many are currently underutilized and some are being mothballed.

In passing, we should note that one of the key features of this system is that it is a financially viable, market-driven system. It is likely that any modification to the system to increase the level of material recovery and recycling should display similar characteristics for it to be viable in the long term. Industry is well aware of the German DUALE system experience where packaging materials are collected, at the expense of the manufacturer (and therefore the consumer), in order to enable recycling. However, the economics of material recycling are unfavourable, with the result that large warehouses of waste packaging materials have been collected, without the reuse links in the recycling chain being viable. This material is now the source of some difficulty for the European Union (EU), as its disposal has adversely affected small-scale, pre-existing recycling operations in other member countries.

2.1.2 Starting Situation: Shredder Refuse

The important requirements made of automobiles, such as safety, performance, reliability, quality, value for money, and environmental compatibility during production, during operation, and during the disposal of disused vehicles are to an increasing degree integrated into automotive construction processes. In addition to design solutions the materials used contribute to meeting these requirements. The possibility of reusing the materials contained in vehicles in the future plays an important role when it comes to selecting the materials and planning the design of new vehicles. Here, however, quality and competitiveness must not be neglected. To optimize the re-utilization of materials detailed investigations of the material-related aspects of automotive recycling are necessary with respect to technology, ecology and economy. The results contribute to the formation of guidelines both for material recycling and design planning of commercial vehicles.

Increasing prosperity of the population in the industrialized countries as well as more and more stringent environmental demands on technology have led to a continuous increase of the amount of

![Fig. 2.1 Existing vehicle disposal routes](image-url)
refuse to be disposal sites is becoming more and more scarce. The increasing number of disused vehicles - in the year 1990 it was approximately two million in Western Europe - contributes to this amount of refuse. Fig. 2.2 shows the currently practiced disposal of disused vehicle. Following the partial disassembly of the re-usable and re-processed components, the body of the disused vehicle moves on to the shredder in pieces the size of a fist. By means of magnetic separation and a process working according to the sink - float process, ferrous metals, non-ferrous metals and non-metallic portions are separated. Whereas the metallic parts move on to a re-utilization process, the non-metallic fraction (25%) - mainly plastics - now as before moves on to a disposal site.

Although the shredder refuse contributes to the overall refuse quantity by only 1.5%, the disposal cost has increased by a factor of three to four during the 1980s, and the tendency goes upwards. The overall automotive industry (including suppliers and disposal plants) is called upon to develop economic and environmentally compatible disposal concepts for disused vehicles.

Fig. 2.3 shows the possibilities to reduce the amount of shredder refuse. They mainly refer to processing and avoiding the refuse. Processing can be achieved by means of thermal recycling, by using an improved and optimized separation technology and the recovery of chemical basic substances. The drawbacks of these processes are the high energy requirement on the one hand, and, on the other, the fact that the amount of refuse would be noticeably reduced only after approximately 10 years due to the lengthy approval phases and/or lengthy, but necessary new process developments.

In contrast, it is possible to reduce the amount of refuse in a much shorter time when concepts are applied which avoid the production of shredder refuse in the first place. These measures are targeted to extended material recycling, particularly in the case of plastics and/or to the increase in the metallic components in the automobile, because metals and their alloys can be recycled at almost 100% by means of re-melting.

Mercedes-Benz AG decided to use a combination of “avoiding processes” to reduce the amount of shredder refuse taking into consideration the different time effects of various technological processes. Fig. 2.4 shows a comparison of the previous “conventional” disposal concept and the Mercedes-Benz recycling and disposal concept. Both concepts are identical including the disassembly step. Reprocessed and re-usable components are removed and move on to a recycling process; for further exploiting this method, new recycling procedures and processes have recently been investigated (Frisch and Razim, 1995).

Following the partial disassembly, the body of the disused vehicle is compressed into bales, cut in pieces using a scrap cutter and subjected to the steel production process of metallurgical recycling.

![Fig. 2.2. Disposal of disused vehicles (today)](image-url)
2.1.3 Specific recycling practices

The additional consideration of quality requirements, particularly with respect to safety, leads to a conflict in materials technology between the components of lightweight construction, safety, environment, resources and costs (Fig. 2.5). The arrangement of the cost components in the form of a tri-

---

**Fig. 2.3 Recycling of dispersed cars: Reducing shredder waste**

**Conventional disposal**

- Old vehicle
- Partial disassembly
- Shredder
- Melting without use of energy

**Concept of Mercedes-Benz**

- Old vehicle
- Partial disassembly
- Waste dump
- Melting without use of energy

---

*Percentage of non-recyclable plastics which must be disposed of by thermal energy recycling

**Fig. 2.4 Disposal of old vehicles**
angular pyramid shows the mutual interdependencies. For this reason it must be the objective of a future material development to comply with all requirements to the same extent, in order to produce high-quality, environmentally compatible and competitive products. In the following, the conflicts between environment/recycling and economy will be explained by the example of the lightweight materials plastic and aluminium.

a) **Plastics** — the use of plastics is inevitable for lightweight construction and safety. At Mercedes-Benz, however, they are used only in places where they offer functional advantages. There are specific challenges as far as the recycling and the re-use of plastics are concerned. One major reason for this is that these materials have a cascade of properties which are particularly distinct when it comes to recycling, and which require high-energy and high-cost processing steps in order to reproduce a component with the same quality.

Fig. 2.6 uses the example of a bumper to show an excerpt of the processing steps from the component to the ground material. An important prerequisite for re-use is that the material is free of impurities and has been segregated in advance; this means that after the initial crushing the metal parts and impurities must be separated. The high-energy grinding processes lead to high processing costs which can be as high as DM 100 tonne.

After the generation of the ground stock, the material is further processed into granulate. This process, as well, contains several stages, such as plastifying, granulating and drying processes which can generate costs of up to DM 100/tonne for each process.

The fuel tank is used as an example to compare the re-processing costs with the costs required to produce a tank from new materials. Since similar processing steps are required for the production of the bumper, the costs for the recycled component are more than 50% higher than for the same component made from new material (Table 2.1). When the disassembly cost of the disused tank is added, the processing costs reach a level of 2.5 times as high as the costs for new material.

These examples make it obvious that re-processing of plastics must be carefully assessed, both for economical and ecological reasons. A condition for the re-use of plastics is the marketability in terms of cost, suitability for use, and the demand on the part of the customers. Taking into consideration the boundary conditions explained, Mercedes-Benz is investigating a large number of plastic components for their re-usability together with suppliers and raw material manufacturers in several recycling projects. However, if these conditions do not prevail, plastic portions should be utilized as an energy medium in thermal and metallurgical recycling processes. In the future, plastic refuse should be dumped on disposal sites only as a last resort.

![Fig. 2.5 Conflicts of materials technology in the automotive industry](image-url)
Tab. 2.1 Processing costs of a plastic fuel tank

<table>
<thead>
<tr>
<th>Processing stage</th>
<th>Cost (DM/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing ground material</td>
<td>0.72</td>
</tr>
<tr>
<td>Regranulation</td>
<td>0.72</td>
</tr>
<tr>
<td>Logistics</td>
<td>0.90</td>
</tr>
<tr>
<td>Overheads and profit</td>
<td>0.59</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2.93</strong></td>
</tr>
<tr>
<td>Removal from scrap vehicles</td>
<td>2.20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5.13</strong></td>
</tr>
</tbody>
</table>

The processing cost of 2.93 DM/Kg is clearly higher than the cost of higher-quality new material (2 DM/Kg).

b) Aluminium accumulated expertise and the use of sophisticated computer equipment have made it possible to optimize lightweight design. This provides a further chance to reduce weight. For various reasons aluminium is a suitable material for lightweight construction. Moreover, it has a high resistance against corrosion which results in a long service life. In the automotive industry aluminium is used in the form of wrought alloys and high-strength wrought alloys for body parts and bumpers and as cast alloys for engine parts and blocks (Fig. 2.7).

![Diagram of plastic recycling and cost analysis](image_url)

Fig. 2.6 Plastic recycling: Costs of the processing stages from the component to the material to be ground
At a first glance aluminium is regarded as a light alloy which is particularly easy to recycle. Although the energy required for the production of secondary aluminium is only 12% of the amount needed to produce primary aluminium, it becomes obvious at a second look that especially the cost for logistics and disassembly steps can make aluminium recycling more expensive than recycling steel which is the main material component in automobiles.

An important prerequisite for aluminium recycling is the segregated use of aluminium components in the above-mentioned aluminium alloy groups. If this segregation is not successful, the aluminium alloys can only be re-used as cast alloys. In addition, only one alloy group is allowed to be used for an aluminium component which can be disassembled.

There are two major possibilities to ensure segregated use: first, specific disassembly with the appropriate segregation, which, however, requires high personnel costs. Owing to the low degree of purity of materials from the conventional sink-float process only cast alloys can be reproduced. Secondly, automatic material sorting using the process of laser detection is currently still being tested, but it constitutes a considerable technical challenge when it comes to achieving the required degree of purity during sorting.

Fig. 2.8 shows a comparison of the costs required to recycle a steel body according to the Mercedes-Benz concept with those required to recycle an aluminium body are almost three times as high as those needed to recycle steel.

c) Metallurgical Recycling taking into consideration the equal ranking of economic and ecological aspects, metallurgical recycling was developed at Mercedes-Benz to dispose of pre-treated and partially disassembled disused vehicles. This recycling process is a steel production process during which a predisassembled disused vehicle from which all re-usable components, units, service fluids and materials were removed, is compressed into bales, cut in pieces using a scrap cutter and is then moved on to a melting process avoids the recombination of pollutants owing to an adapted temperature control. The advantages of this system are that environment-polluting substances are avoided,
the energy contents of the organic substances remaining in the body of the disused vehicle are utilized (saving primary energy of up to 30%), their carburization effect, and that the inorganic components are used as a flux making slag.

The utilization of the materials which cannot be recycled results in an additional protection of raw materials and resources. With this process which was further developed and prepared for large-scale technical implementation in cooperation with Voest Alpine Stahl AG as part of a research company, the loop of disused vehicle disposal can be closed avoiding environment-polluting residues and refuse.

2.1.4 The ACORD process

A strategic level response from industry to address these issues was the formation of ACORD, the Automotive Consortium on Recycling and Disposal. ACORD has brought together motor manufacturers, members of the British scrap industry, the vehicle dismantling industry, Government departments including DTI, DoE and DVLA. They share the objective of minimizing the environmental impact of end-of-life vehicles (Renfree and Nosken, 1998).

Based on EU recommendations, the properties for vehicle recycling are defined as:

1. Prevention. Wherever possible the need for recycling should be avoided by efficient design and manufacturing processes. For the motor industry, one way to achieve this is by designing to achieve longer life for its products, for example improved corrosion protection, enhanced reliability.

2. Reuse of parts. Thus components and assemblies removed from ELVs should be reused wherever it is safe and economic to do so. Alternatively, parts and assemblies should be refurbished or remanufactured wherever possible.

3. In the absence of opportunities for reuse, material recycling should be carried out. Thus materials should be recovered from the vehicle and reprocessed to make it suitable for manufacture of new components wherever it is technically and economically feasible.

4. Energy recovery should be practised on materials that are impossible to utilize in any of the above strategies.

5. As a final resort, disposal of the material would be in landfill or similar.

The project is examining the following key areas:

1. Cost effective disassembly. The project is investigating the techniques, tooling and facilities that would be required for the rapid dismantling of a range of British marketed vehicles (not just Rover).

![Fig. 2.8 Cost estimate for recycling: Steel body and aluminium body (incl. logistics costs)](image)

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Drainage of service products
Packaging
Metallurgical recycling

Delivery to processing plant
Drainage of service products
Disassembly
Aluminium shredder
Sorting of scrap
Remelting
Thermal use of light shredder waste

Steel
Aluminium
2. A database for material recovery and identification. The ability to identify material recovered from the range of vehicles to be dealt with forms a key requirement for successful recycling.

3. Markets for recovered materials. Any business activity requires the existence of markets of suitable size for the products it is able to generate.

4. Post-disassembly materials processing. This sector of the project investigates potential enabling or value adding activities that may be carried out between disassembly of the vehicle and delivering the resulting materials to the recycler.

5. Infrastructural and economic issues.

6. Principles of design for recycling. In general, none of the car manufacturers’ design practices have historically included disassembly and recycling as an objective. The project is endeavouring to establish design rules to achieve features that optimize material recovery and recycling opportunities for end-of-life vehicles.

The process proposed by ACORD is illustrated in Fig. 2.9. The last user needs to be either encouraged or required to give up their ELVs to an authorized disposer. The disposer would drain the vehicle fluids and strip parts for recycling. Such parts would be either components/assemblies for reuse/refurbishment or materials for recycling. The level of stripping should, in all cases except fluids, be driven by market forces. Parts for reuse or refurbishment are sold to the public or to appropriate organizations, for example component refurbishers and reconditioners. Non-metallic materials are passed to appropriate materials recyclers and the remaining metallic components, complete with non-metals that it has not been economic to remove, enter the existing scrap metal industry at an appropriate point in the relevant value chain. The scrap metal processor would then shred the vehicle shell as currently and either landfill the shredder residue or, if possible, pass it to an energy recycling operation, the ash from which would then be landfilled.

A number of controls are necessary in the process. Thus there will be costs associated with meeting the disposal standards - for instance ensuring that vehicle fluids are not allowed to contaminate the environment. While the enforcement of such standards is the responsibility of the local Waste Regulation Authority in compliance with the Environmental Protection Legislation, the last user should be able to recognize an authorized disposer. This may be achieved by utilizing a Certificate of Disposal, which will help to ensure that the vehicle enters the licensed disposal chain. In doing so, it will protect disposers who operate in an environmentally acceptable fashion from unfair competition. The certificate will also define the point at which vehicles become scrap. By requiring the disposal certificate to be returned to DVLA, greater control of vehicle identification records will also be achieved.

ACORD also recommends the establishment of an expert body. This would involve government, the disposal industry, material supplying industries and the vehicle manufacturers. The group would recommend standards for the improved disposal process and disseminate information on process and materials to the disposal industry and regulatory authorities. Inputs to the group would be dismantling manuals for different models of vehicle from the manufacturers and indication of the standards required for recovered materials from the material recycling industries.
Fig. 2.9 Proposed ACORD operation plan process
Chapter 3
Materials evolution in the automotive industry

3.1 The main changes in the materials content

In considering the recycling of ELVs, it is first necessary to understand the variety of material types utilized in cars. A number of slightly different views of these data have been presented. The graph in Fig. 3.1 represents a reasonable aggregate view. Proportions of different materials will of course vary from one manufacturer to another and by vehicle purpose, size, trim level, manufacturing volume and many other parameters, all of which play a part in material selection.

It is therefore evident that over the past 15 years the metallic content of vehicles has reduced, while non-metals, including plastics, have increased. It is interesting to note that in recent years the weight of automobiles has tended to increase, undoubtedly due to the higher specification levels demanded by the customer and in some instances by legislation, often safety related. One of the results of this from a commercial perspective can be seen by considering the position of the shredder operator, who derives his or her income from the metallic materials that are recovered from the ELV. Against these are set the costs arising from plant operation and disposal of the shredder waste via landfill. Thus, the reduction in metallic materials and increase in plastics and other non-recoverable materials over the period will decrease basic profitability. Further, considering that the scrap industry is currently dealing with ELVs with an average age of around 13 years, it is evident that this situation will become appreciably worse unless alternative sources of income can be found from ELVs.

The first significant changes in automotive materials during this period took place in the early 1960s, in part due to the industry’s new emphasis on corrosion resistance. Aesthetic damage due to corrosion, which in turn could be traced to the increased use of road salt, had become a marketing problem. Ford, for example, began to use galvanized steel during these years for this reason. At the same time, the auto manufacturers began to make extensive use of plastic components, primarily for non-structural applications such as window cranks, heater ducts and knobs. In the early 1970’s, plastics began to be used extensively for grills, fan shrouds, wheel-well liners and structural applications.

![Fig. 3.1 Materials content of motor cars by year](image-url)
where their corrosion resistance and lower density could be an advantage (Niemczewski, 1984).

### 3.2 Industry response

To respond to the growing consumer preference for high-mileage cars, the auto industry has had to use a wide range of strategies. These strategies can be divided into three principal categories:

- **Vehicle design and materials programs**;
- **Drivetrain improvements**;
- **Engine improvements**.

**Vehicle Design and Materials Programs**

Vehicle design and materials programs include most of the generally-known fuel-economy strategies, principally materials substitution, downsizing, downweighting, aerodynamic design, and a few lesser-known strategies, such as rolling resistance reduction and lubrication improvements. These strategies all have to do with vehicle body form and function, and they are often used together.

**Materials Substitution.** The replacement of a car’s heavy component materials, such as cast iron, with lighter and stronger materials, such as aluminium, is likely to be one of the most significant technologies in improving automobile fuel economy. In addition to the direct loss of weight in a given part, materials substitution leads to a cumulative weight loss effect. For example, a lighter hood requires lighter hinges and springs, which in turn can allow other underbody weight reductions, a lighter engine due to lower power requirements, etc. Some degree of materials substitution is necessary to produce the fuel-efficient cars required by government and demanded by consumers because the technologies described above cannot do so alone. Only downsizing offers, in the short term, any considerable potential for additional improvements in fuel economy at a reasonable cost, and such a strategy is not practicable because consumers still demand a comfortable vehicle which performs well.

**Iron and Steel.** As noted above, despite the increasing use of aluminium, plastics and other materials in automobiles, the metals most often used in automotive applications are iron and steel. Steel has properties that make it ideal for many automotive applications, such as its broad range of strengths and the ease with which it can be joined, formed and painted. It often costs less, on a per part basis, than competing materials, and it is compatible with implant processing equipment. Moreover, automotive engineers currently have more knowledge of and experience with steel than with any other material. Thinner gauges, parts consolidation and high strength steels allow design engineers to lighten almost any steel application. Steel could even be used for non-traditional applications such as manifolds, engines and brake drums.

The selection of automotive materials has always been a lengthy and complicated process. In prior years the principal criteria were: the demands imposed by the intended use of the material, cost, manufacturability, and availability. Requirements of intended use could include such factors as strength, corrosion resistance, dimensional stability, toughness, appearance and heat resistance. Obviously, different applications have radically different requirements. For example, the material for the hood is examined in terms of outer appearance, vibration, and locational instability, while material for an engine bracket is evaluated primarily in terms of elastic deformation at high levels of loading. Manufacturability generally has to do with how easy it is to shape the material and join it to other materials, and includes factors such as machineability.

The decision on which material to use for a specific application was made on the basis of which of the materials with the required properties had the lowest cost. Since the introduction of the fuel economy standards, however, become a more important factor than its cost. The single most important guideline is now cost per pound of weight saved. In a survey conducted by Arthur Andersen and Company, automotive engineers estimated that a pound of weight saved was worth 90 cents per car in 1979, $1 in 1985 and $1.25 in 1990 (in 1979 dollars).
The other important factor underlying changes in automotive materials is the recent market shift toward smaller, more fuel-efficient cars. As noted below, however, this shift may not have been permanent.

Consumer demand for automobiles has traditionally been a function of such characteristics as appearance and power. While some ridiculed the fins on the automobiles of the 1950s and many proposed that Americans do or should want cheap, safe, reliable transportation, this was not evident in the marketplace. Ford tried to sell such a car in the 1920s and failed. Similar attempts by manufacturers in the late 1940s, in the 1960s and 1970s had the same result. When given a choice, the vast majority of new car buyers chose an automobile on the basis of style, power and comfort. This perception of the automobile has changed only recently, due to rapidly rising fuel prices and persistent doubts about the future availability of gasoline.

Following the OPEC oil embargo of 1973-74, there was a temporary surge in the demand for such small cars. Then the oil glut of 1978 and the effect of artificially depressed gasoline prices caused the market to move in the other direction. Starting in 1979, however the demand for fuel efficient cars increased rapidly as world oil prices, coupled with the first phase of oil price decontrol, pushed U.S. gasoline prices to record levels. This effect was exacerbated by temporary gasoline shortages. Between 1970 and 1980, the markets held by compact and sub-compact models rose from 36 percent of total new car sales to 60 percent.

The overall market swing toward fuel efficient cars has concentrated sales in a segment of the market where U.S. manufacturers have historically competed on a very limited basis. Foreign manufacturers, in contrast, due to higher fuel costs in their home countries, have produced a variety of small, fuel-efficient automobiles. In 1979, while most of the compact cars (i.e., cars about 170-200 inches long and 100-110 cubic feet of interior space) in the U.S. market were American-made, two-thirds of the subcompacts (140-170 inches long and 85-100 cubic feet of space) were imported. With this advantage, imported car sales have climbed to their recent high of 32.8 percent of the total U.S. new car market.

While iron and steel will remain the principal automotive materials, there will be major changes in the types of ferrous metals that are used. The use of cast iron will decrease, even though it is inexpensive and familiar, because of its weight. Some low carbon ("mild") steel will be replaced by high-strength steels, including high-strength low-alloy steels (HSLA) and dual-phase steels which are 20-400 percent stronger and can save between 10 to 25 percent in weight. Stainless and other types of steel are expected to remain approximately constant as a fraction of total weight.

High strength steels are expected to increase from 9 percent to 12 percent of the total weight of the average automobile between 1980 and 1985. Chrysler’s Omni/Horizon, for example, already uses HSLA extensively in such applications as frame sections, windshield pillars, and brake pedals. On Ford’s Fairmont and Zephyr, HSLA is used in suspension systems, bumpers, and engine mounts.

All of these HSLA applications are characterized by the need for dynamic strength. To some extent, what HSLA has gained in strength it has lost in ductility relative to mild steels. Dual phase steels can provide the strength necessary to handle these applications while retaining the ability to be formed relatively easily into automotive components.

**Aluminium.** Despite steel’s traditional place in the automotive industry, some automakers reportedly believe that the use of even the new high strength steels will peak because aluminium and plastics will begin to take over the major weight reduction role. Aluminium alloys have about one-third the density of steel. An aluminium cylinder head, for example, weighs about 30 pounds less than one made of cast iron.

Two factors stand in the way of increased use of aluminium. The first is cost. Aluminium is more expensive than steel, and it is more energy intensive and so more sensitive to changes in energy prices. The second factor is stiffness. If stiffness is a necessary property in a given application, an aluminium part may demand more material than a comparable iron or steel part. Therefore, aluminium
will be first used in parts of the automobile not subject to much stress, such as cylinder head, manifolds, brake drums and pumps.

**Plastics and composites.** In automobile applications, plastics save approximately one pound of weight for every pound that is used. Moreover, plastics are often cheaper to produce than the steel or zinc parts that they replace. (Plastics are also competitive with aluminium in many applications, for example, exterior panels). Currently, plastics are used in non-load bearing applications such as interior trim, radiator grilles, and flexible bumpers. Fiber-reinforced plastics can bear stress, but are currently too expensive (around $20 per pound) for extensive use. If the cost can be significantly reduced, they could be used for load-carrying applications such as drive-shafts, springs and wheels.

**Magnesium.** Magnesium per volume weighs about two-thirds as much as aluminium. It has better castability, machinability, finish, and damping capacity for parts under stress. Its shortcomings include susceptibility to corrosion and low tensile strength, but the major impediment to its increased use is its relatively high cost (about $1.34 per pound) compared with that of aluminium (about 76 cents per pound). Even on a volume basis it is 17 percent more expensive than aluminium. Were it not for this cost disadvantage, magnesium die castings could replace aluminium in many applications. Currently, the Chrysler Omni/Horizon and the VW Rabbit have magnesium transmission cases. Ford uses magnesium steering column lock housings and window sill mirror plates. On average, though, very little magnesium is used in automobiles now being produced. This usage is projected to increase to 3 to 5 pounds per car by 1985, and to double that by 1990.

**Zinc.** Applications such as door handles, locks, body hardware, trim, and lamp and lighting fittings used to be the sole province of zinc metal, because of zinc's castability. However, many of these zinc parts have been replaced by plastic parts as a weight reduction measure. In 1977 the typical automobile had 40 pounds of zinc, down from 60-70 pounds in the 1950's and 1960's. The 1981 model year U.S. automobile had only about 23 pounds of zinc, it's 1985 counterpart will have 20 pounds at most, and the 1990 automobile about 15 pounds.

**Other materials.** Approximately 14 percent of the weight of a 1995 model year automobile is accounted for by other materials. These include copper, lead, nickel, chromium, platinum, rubber fabric and glass. Downsizing will reduce the weight of some of these materials. Proportionally, most will remain constant since they are not major components of car weight.

**Vehicle Downsizing.** The current phase of vehicle downsizing dates back to at least 1975, when General Motors began to design smaller versions of established models. Downsizing usually involves reducing the wheel base and the front and rear overhang. It may also involve increasing the vehicle height. Typically, such programs also reduce weight through design and materials substitution, as well as the iterative effect on the weight of other vehicle components. Vehicle aerodynamics may also be improved as part of this process, even though downsizing gives cars a more rectangular shape in order to increase their volumetric efficiency. Between 1980 and 1985, it is estimated that downsizing alone will improve the weight of the average new automobile by 12 percent.

**Weight Reduction.** Weight reduction is achieved by redesigning vehicle components to a more highly optimized set of specifications. That is, a particular part is designed to perform the same function in the vehicle while using less material to save weight. The engine block, which is the single heaviest component in a passenger automobile, provides a good example both of how much weight can be reduced in this way and how this affects materials substitution. Most engine blocks are still made of cast iron. An obvious alternative material would be aluminium, but this is much more expensive and difficult to machine than cast iron. Therefore, considerable effort has gone into redesigning engine blocks to reduce their weight, by removing non-functional metal while still using cast iron. This has involved thin-wall casting. The 1976 Pontiac V-8 engine weighed 61 pounds less than did the 1975 model solely due to such a redesign. More recently, the 1982 Nissan Stanza two-liter engine was redesigned to eliminate 66 pounds from the engine block by reducing the space between the four cylinders. Moreover, the then-shorter engine made room for a new, lighter and more
compact transmission behind it. That eliminated more weight and enabled Nissan to enlarge the passenger area.

**Aerodynamic Design.** Aerodynamic drag is a function of a car’s frontal area and overall body shape. The coefficient of drag, or CD, in late model vehicles is about .45. A 1982 Pontiac Firebird has a CD of .31, with a difference in fuel consumption roughly equivalent to a weight reduction of 600 pounds. Minor changes in body styling and other details, it is estimated, will improve fuel economy by 3 to 5 percent between 1980 and 1985. In addition to body design changes, items such as front and rear spoilers, streamlined mirrors, and improved wheel covers could be added to a vehicle to reduce drag. Major improvements in the coefficient of drag, however, will require the total redesign of the vehicle.

Other vehicle improvements involved the related areas of **rolling resistance reduction** and **lubrication.** Rolling resistance reduction will entail such factors as improved tire design and reduced disk brake drag. Lubrication includes reduced viscosity and friction-modified engine oils, and improved lubrication of transmission, differentials and wheel bearings.

### 3.3 Materials for solving problems in automotive engineering

The trends mentioned above necessitate designs that go into all details and bring up the question of what the most suitable materials will be. In automotive engineering, materials offer the key to solving many problems. Plastics have opportunities even in fields where other materials are superior. They are assessed by the same yardsticks as those adopted for classical engineering materials, although they do not have such a long tradition.

However, many plastics and parts produced from them have already proved their worth over long periods of time. Adequate experience has been gained on their long-term performance, e.g. their resistance to outdoor exposure, chemicals and heat and their mechanical strength.

The information that can be gained from computerized forecasts grows in proportion to the knowledge obtained about the relationship between time and temperature and the physical and mechanical properties. Modern software, e.g. the method of finite elements, permits complicated stress-strain relationships to be reliably predicted (Weber, 1991).

Other simulation techniques, e.g. Moldflow and Cadmold, permit mould-filling mechanisms to be analyzed and predicted mathematically. Thus, orientation and other processing parameters that affect

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Fig. 3.2 Plastics markets in the West (in %)
the properties of the mouldings can be reliably detected and embraced in the calculation. It is even possible to exploit anisotropy in optimizing a part.

Processing techniques for plastics - e.g. compression, injection and blow moulding; extrusion and thermoforming - permit large production runs. The raw materials and the parts produced from them satisfy the demands on quality imposed by the automobile industry.

3.4 The part played by plastics in automotive engineering

Automotive engineering accounts for roughly 7%, (less than 10%), of the plastics consumed in Western countries (Fig. 3.2). Nevertheless, the automobile industry represents an attractive market for plastics because it occupies a key position in technical development and instigates numerous important technical ideas.

The average proportion of plastics in automobiles is currently of the order of 10%. A proportion of 12% is anticipated for the next few years in conservative estimates, and optimists forecast 14%.

![Fig. 3.3 Growth rates for main materials used in automobiles during the period 1965-95 (in %)](chart1.png)

![Fig. 3.4 Growth rates for the mass fraction of plastics in various vehicles from the one manufacturer.](chart2.png)
The growth rate of plastics in automotive engineering over a period of 30 years is evident from Fig. 3.3 and figures for individual models can be derived from Fig. 3.4.

The amount of plastics currently consumed in automotive engineering in Western Europe is of the order of 1·35 million metric tonnes; a breakdown into the individual product groups is presented in Fig. 3.5 (Weber, 1991).

A striking fact that emerges from this diagram is that polypropylene and polyethylene, both of which are comparatively easy to recycle, account for more than one-third of the amounts of plastics used in automobiles.

It can be seen from Tab. 3.1 that annual growth rates of 5% or more can be expected for high-grade engineering plastics in the next few years. Hence, the automobile industry is an important partner for the plastics industry and applications in automobiles represent an attractive market. This applies not only to raw materials manufacturers, who offer the automobile industry partnership in development projects (Tab. 3.2), but also to the suppliers who process more than 80% of the plastics used in automotive engineering. In Western Europe automobile manufacturers with extensive facilities of their own for processing plastics, accounted for 17% of the total 1·35 million tonnes of plastics processed for the automobile industry in 1989.

The automobile industry is currently reorganizing its development and manufacturing processes in order to cope with the increasing severity of competition and to face the Japanese challenge. The demands that are thus imposed by European automobile manufacturers have their consequences for suppliers and raw materials manufacturers.

### 3.5 The properties of plastics that affect automotive engineering

The following properties of significance in automotive engineering:
- density
- tensile strength and rigidity
- impact resistance
- resistance to heat deformation

![Fig. 3.5 Western European consumption of plastics in automotive engineering in 1989](image)
resistance to high-temperature aging
resistance to ultraviolet radiation resistance to chemicals

a) Density, tensile strength and rigidity, and impact resistance

The modulus of elasticity is an expression for the strength and rigidity of a material and directly governs the dimensions of a part. The greater it is, the thinner and thus the lighter the article may be. An advantage of plastics is that their density is very low, i.e. between 0·9 and 1·9 g/cm³.

The impact resistance is a measure for the amount of energy that can be absorbed by a material before the part concerned fails under given criteria. It is thus a characteristic that represents the reserves of safety in a material.

As a first approximation, the three parameters - tensile strength, modulus of elasticity and impact resistance - govern a part’s load-bearing capacity and thus its dimensions. They are therefore directly related to the weight, which - in turn - is connected with the energy requirements, running costs
and outlay for recycling. Lightweight structures are a basic requirement in automotive engineering. A low mass entails less force in acceleration and deceleration and thus a lower fuel consumption and less wear and tear of brakes.

Although weight-saving does not enjoy the same priority in the automotive engineering as it does in aircraft and spacecraft construction, it remains an urgent problem, because demands on comfort in the shape of air conditioners, power steering, etc., are making a growing contribution to the weight of motor vehicles.

Plastics have adequate to good strength and rigidity - or even excellent in the case of advanced composites - in addition to a low density. Thus, they hold out a two-fold opportunity for meeting automobile manufacturers’ demands for savings in weight. Consequently, plastics improve performance and road-holding and contribute towards greater comfort and safety.

The impact resistance varies considerably from the one type of plastic to another, and allowance must be made for this fact in selecting materials. The choice ranges from decidedly brittle products to very ductile materials. For instance, high-molecular-weight polyethylene is an extremely tough material that is eminently suitable for the production of fuel tanks.

Poly(methyl methacrylate) (PMMA) is very brittle, but is indispensable in automotive engineering because of its optical properties and its extremely good outdoor performance. A recent innovation has been to modify PMMA so that it becomes impact-resistant. Modifying plastics by elastomers and blending different types permit the dividing line between brittleness and ductility in the various classes of products to be shifted with an attendant increase in scope.

More detailed information is given in raw materials manufacturers’ information systems. An example is CAMPUS (computer aided materials presented by uniform standards) by menas of which the four major German plastics manufacturers and a number of raw materials suppliers from other countries present their computerized data. The information allows a material to be selected in the light of the initial considerations and the various products to be compared with one another.

However, a line must be drawn between all the information available for a given material and the properties of any part produced from it. These properties are affected by a number of other factors. For example, the amount of energy that can be absorbed by a bumper is undoubtedly governed in the first instance by the material of construction, but is also considerably influenced by the design and geometry.

The bumper may be designed as an inflexible shell with an energy-absorbent core of a plastic foam. Alternatively, it may consist of a sheet-metal compound, (SMC), or Glassmat-reinforced thermoplastic (GTM) beam of great flexural strength clad in accordance with the stylist’s requirements by a sheath produced from a plastics foam is interposed between the beam and the sheath.

Designers must be warned against excessively rigid adherence to tabulated figures for the properties of materials, and this applies even more to plastics than to others. Frequently, the free scope in design that is allowed by plastic; may compensate for apparent weaknesses in the material.

Manufacturers’ materials information systems also embrace the functional relationships systems also embrace the functional relationships that exist between time, temperature and the properties of the materials. Tabulated data must be regarded merely as an initial guide, because the values required for accurate design calculations always depend on time, temperature and other parameters.

b) Resistance to heat and outdoor exposure

Various automobile parts are exposed to high temperatures. In the passenger space, this applies to the instrument panel underneath the windscreen; in the chassis, to the vicinity of the brakes; and in the engine compartment, to the transmission and exhaust gas systems. Bodywork parts are subjected to high temperatures on the coating line.

Apart from a few spectacular experimental designs, no plastics versions exist for exhaust gas systems, brakes, cylinder blocks, pistons and valves. Plastics have been successfully adopted for all oth-
er automobile parts.

The paintwork raises questions of a special nature. The trend towards lower baking temperatures favours the use of plastics. However, only a comparatively few specially developed types can meet the requirements imposed in on-line coating. Examples are low-profile SMC and bulk moulding compound (BMC) systems (Fig. 10) and polyamide/poly(phenylene ether) blends (PA/PPE).

Great progress has been made in coating plastics for interior trim. The motto in this case is a ‘soft touch’.

If the stylist has no objections, a number of plastics can dispense with protective coatings, because their outdoor performance (i.e. resistance to changes in shade, greying and chalking) meet all requirements. In this connection, particular attention is drawn to acrylonitrile styrene acrylate (ASA) polymers and their blends, from which radiator grilles, air inlet louvres, number plates, and many other parts have already been successfully produced.

Class A finishes are specified for bodywork parts. Low-profile SMC and BMC techniques have been developed to this stage and have been adopted on a production-line basis by various automobile manufacturers.

On average, the thermal expansion of thermoplastics is about seven times greater than that of steel. Hence, if both types of materials are present in composite structures, differential expansion occurs and must be counteracted by design measures. In this respect, glass-reinforced thermoplastics and thermosetting plastics do not present any difficulties, because their thermal expansion differs only slightly from that of metals.

In the assessment of plastics parts, the automobile industry assigns top priority to the economics of production, and even weight reduction and the free scope allowed in styling are considered to be of subordinate importance. The most striking advantage of plastics processing techniques (e.g. compression, injection and blow-moulding and in-situ foaming) is that they allow very complicated, multifunctional parts to be produced in the one operation and that these parts require very little finishing, if at all. Furthermore, these production techniques permit close adherence to tolerances.

3.6 Evolution in elastomers application

Consumer products, sporting goods, automotive components, wire and cable, industrial equipment, and biomedical devices. These, indeed, represent a diverse range of products. But, in many instances, they have one important element in common-thermoplastic elastomers (TPEs).

The reasoning behind TPEs’ choice is not hard to understand. They are a versatile group of resins. Consider, for example, some of their innate property characteristics:

- These linear segmented polymers consist of hard and soft ingredients. By varying the relative amounts of the hard and soft components, the resins can meet a wide range of flexibility and performance requirements. This choice alone lets engineers optimize the material to match design criteria when it comes to everything from color or clarity to indoor or outdoor uses.
- They are environmentally friendly. Recent resin introductions have expanded this friendliness to include improved recyclability and non-toxin-containing formulations.
- Advances in processing technology enable TPEs to be tailored to meet almost any design need, while improving product quality and cost.

Wrap these features in a package and it’s little wonder that TPEs have become an increasingly popular entry on the design engineer’s material list.

To better illustrate this adaptability, let’s look at two industry areas-automotive and medical-where TPEs are making serious inroads as replacements for metals or to complement other plastic materials.

Automotive electronics provide a perfect example of how TPEs can adapt to the changing design needs. The explosion of electronic features in today’s automobiles has caused a corresponding in-
creare in the size of electric wiring harnesses. Packaging constraints due to this trend are driving a
downsizing of electrical systems. Engineers have accomplished this in two ways: reducing conduc-
tor wires, which results in higher operating temperatures, or reducing the thickness of the insulating
materials, which requires the need for greater insulating efficiency.

DSM Engineering Plastics has introduced a series of TPEs, Arnitel® V, that address the needs of
both problems. Arnitel UM551-V, a non halogenated, flame-retardant grade, answers the primary
wire insulation obstacle, while Arnitel UM552 fulfills the need for components that require high-tem-
perature resistance, but not flame retardancy.

DSM, the Netherlands-based parent of DSM Engineering, acquired the Arnitel product line from
Akzo in 1991. In Europe, Arnitel U has replaced PVC and cross-linked polyethylene based on its en-
vironmental, process, recycling, and performance advantages. Relative to other polyester elastomers
and typical wiring insulation materials, says Steve Hartig, DSM Engineering Plastics’ automotive in-
dustry manager, Arnitel can offer:
- Continuous-use temperature capability for natural materials up to 338°F (170°C), and for non-
halogenated, flame-retardant grades up to 302°F (150°C).
- Twice the abrasion resistance.
- Excellent UV stability and color fastness.

“We have the expertise of our TPE division here in the U.S., and the experience of thermoplastic
manufacturing in Europe”, Hartig adds. “This will enable Arnitel UM551-V to find an important
niche in automotive under-hood cabling systems”.

And when it comes to heat- and oil-resistant materials, particularly for such automotive applica-
tions as O-rings, seals, and gaskets, don’t overlook a new class of speciality elastomers from DuPont.
The Advanta™ 3320 and 3560 materials consist of compatible alloys of proprietary polar ethylene
copolymers and fluoro-elastomers. They are peroxide-curable, whereby the same cure system
cocrosslinks both components.

Using the new SAE standard J2236 for determining continuous upper temperature resistance, Ad-
vanta 3320 qualifies as a 165°C material, and Advanta 3550 as a 175°C material, with intermittent ex-
cursions to 200°C. “Current lab work promises further improvements in long-term heat resistance”,
says Eric W. Thomas, senior development specialist at DuPont Elastomers. Processing includes stan-
dard compression, transfer, and injection molding techniques. Bonding metal and plastics substrates
is possible using commercial primers and bonding agents.

There’s also a new family of highly cross-linked, dynamically vulcanized TPE compounds for the
automotive market. Introduced by the Plastics Div. of Teknor Apex Co., the Uniprene® 7000 TPE
olefin-based compounds “have physical characteristics, appearance, and feel similar to vulcanized
rubber, but offer superior performance versus competitive products in a wide range of demanding en-
vironments”, says Thomas Moccia, TPE market development manager.

The materials come in hardness grade of 55 Shore A to 40 Shore D. And, because these products
are not hygroscopic, they require no drying. “Additionally, they are readily curable, 100%° recy-
clicable, and heat stable up to 232°C”, Moccia adds.

The increasing popularity of airbags is another automotive area where TPE’s “elastic” properties
play a major role. In one case, it helped Chrysler save $12 million a year in the production of driver-
side airbags.

For this project, Chrysler worked with Advanced Elastomer Systems (AES) and other team mem-
bers that included Morton International and Venture Industries. The design involved converting the
airbag door from a thermoset to a thermoplastic. The savings resulted primarily from a 40% decrease
in the weight of the doors and lower resin costs. However, the simplified design also proved a key
factor in the cost savings.

The doors had been made out of reaction-injection-molded, SCRM-reinforced urethane. They
were riveted onto the airbag module. Morton developed a design that uses AES’ Santoprene® ther-
moplastic rubber to injection-mold a lighter, easier-to-assemble door that snap-fits to the module.

“Morton reviewed 26 thermoplastic materials before selecting Santoprene as offering the best balance of properties for the application”, says Bonnie R. Benny hoff, AES’s account manager for Chrysler. “Specifically, Chrysler was impressed with the ‘look’ and ‘feel’ of the material, and with its ease to process. And we have already delivered test samples that will lead to the next generation of airbag door materials”.

And TPEs have one other thing going for them in the automotive world. This market has a focused priority to address recyclability issues, with elastomeric products one focal point. It is expected that the activity in this market segment will carry over into other durable goods markets in setting the pace for dealing with the afterlife and reuse of products.
Chapter 4
Separation Techniques for Auto Shredder Residue

4.1 Introduction

Disposal of automobile shredder residue (ASR), remaining from the reclamation of steel from junked automobiles, promises to be an increasing environmental and economic concern. Argonne National Laboratory (ANL) has investigated alternative technology for recovering value from ASR while also, it is hoped, lessening landfill disposal concerns.

Of the ASR total, some 20% by weight consists of plastics. Preliminary work at ANL is being directed toward developing a protocol, both mechanical and chemical (solvent dissolution), to separate and recover polyurethane foam and the major thermoplastic fraction from ASR. Feasibility has been demonstrated in laboratory-size equipment.

Each year the secondary metals industry recovers about 36 million metric tons of ferrous scrap, which is used in the production of finished steel products. The single largest source of this scrap is the obsolete automobile, with the auto shredder industry recovering some 9-11 million metric tons. For each ton of steel recovered, however, some 275 lb (125 kg) of residue is generated. This auto shredder residue (ASR) is composed of the nonmetallics content of the automobile. It contains the expected materials such as plastics, glass, rubber, fibers, foam, as well as dirt, gravel and sand. It is also contaminated with brake fluid, steering fluids, motor oils, gasoline, heavy metals, and in some cases PCBs resulting from the shredding of “white” goods (refrigerators and other appliances) with their capacitors intact. The plastics content of ASR is typically about 20% by weight in about a 3-1 ratio of thermoplastics to thermosets. The plastics content of ASR is expected to increase over the next decade due to the significant increase in the use of automotive plastics over the past 10-15 years.

At present, ASR is landfilled. The rapidly escalating landfiling costs, along with environmental concerns over the contaminants and the fate of this waste in the landfill, are encouraging the search for cost-effective alternatives to landfiling. Research has and is being done meanwhile to identify and develop recycling technologies which will reduce the volume and mass of ASR going to landfills and neutralize or reduce its level of contamination to acceptable values, thereby reducing the costs associated with the landfiling of ASR.

It appears that the plastics component of ASR, which is expected to increase significantly over the foreseeable future, is an especially attractive target for realizing value from ASR. Realization of that value will vary according to whether ASR’s plastic content can be recovered in a commercially viable form (primary or secondary recycling) or alternatively can be sufficiently concentrated to capitalize on its hydrocarbon structure and its high energy value (tertiary or quaternary recycling).

Recycling modes are defined below:
- primary: recovery of “pure” plastics
- secondary: production of “lower-grade” products (e.g.) park benches
- tertiary: production of fuels and chemicals
- quaternary: production of heat and/or electricity

The purposes of this chapter are: (1) to call attention to the significant and ever increasing plastics waste stream that is becoming available within ASR; (2) to outline briefly the technology associated with automobile materials recycling and possible access routes to their discarded plastic components; (3) to report on preliminary ASR separation techniques involving physical and solvent dissolution separation means; and (4) to speculate on possible approaches to reconstituting useful phys-
ical properties for recovered thermoplastics.

The content of plastics in automobiles has been steadily increasing for a variety of well-known reasons. Some of these reasons include weight savings of plastics over metals (fuel economy), design freedom for car manufacturers, simplified labor assembly procedures, corrosion and rust resistance, etc. There is little reason to believe this trend may be reversed, although conceivably, its rate of increase may be slower. At the present time some 250-275 lb (112-125 kg) of plastics and polymers are used in a 3500 lb (1590 kg) automobile, and some estimates reach 15% of a car’s weight by 1995. Because discarded automobiles are a desirable raw material source of ferrous scrap metal for the iron and steel industry, it follows that automobile shredder residue (ASR) could itself serve as a resource for the very valuable plastic residue it contains.

Automobile Shredder Residue - 1982 (Basic Statistics):
- Number of cars** to shredders - 5 to 6 million;
- Average weight of plastics per car - 200 lb (90.6 kg)
- Estimated weight of plastic scrap - 0.5 to 0.6 million tons (453 to 543 x 10^6 kg)

The main types of plastics used in U.S. automobiles (1985) have been the following:

<table>
<thead>
<tr>
<th>Plastics</th>
<th>Amount (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyurethane</td>
<td>22.6</td>
</tr>
<tr>
<td>ABS</td>
<td>7.3</td>
</tr>
<tr>
<td>Acrylic</td>
<td>2.5</td>
</tr>
<tr>
<td>Nylon</td>
<td>3.7</td>
</tr>
<tr>
<td>Phenolic</td>
<td>2.1</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>19.2</td>
</tr>
<tr>
<td>PVC</td>
<td>15.5</td>
</tr>
<tr>
<td>RP, BMC, SMC</td>
<td>21.9</td>
</tr>
<tr>
<td>Other</td>
<td>5.2</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

As can be seen from the above data, thermoplastics account for the major portion of the plastic scrap. It is that thermoplastic component for which Argonne National Laboratory (ANL) is considering separation techniques based on mechanical and solvent separation techniques.

### 4.2 Automobile recycling

The single largest source of recycled ferrous scrap is the obsolete automobile. Fig. 4.1 summarizes the processes involved in the recycling of a scrapped automobile (Bonsignore et al., 1993).

![Fig. 4.1 Processing of obsolete automobiles](image-url)
In 1988, the 200 or so shredders in the U.S. supplied in excess of 9 million metric tons of recovered ferrous scrap to the iron and steel industry.

**Automobile Shredder Industry.** The major investment of a shredder operator is in the shredder machine itself. The machine (typically driven by a 3000-6000 hp motor) shreds auto hulks into fist-sized chunks. Downstream from the shredder are the magnetic separators and air classifiers. The shredded automobiles end up in three major fractions: ferrous scrap, nonferrous scrap and ASR. Although the value of the ferrous and nonferrous scrap has increased in the recent past, the cost of disposal of ASR has skyrocketed from about $5 per ton in 1985 to over $100 per ton in some areas in 1990. As landfill space is becoming very scarce, disposal costs can only be expected to increase further. As a result, disposal of ASR accounts for an ever increasing operating cost relative to income from the metals recovered. Unless a technology to handle ASR is developed, it will affect the viability of this industry.

Escalating disposal costs will affect the price and/or supply of high quality ferrous scrap. Also implied is the thwarting of access to the contained plastic resource in ASR.

**Automotive Dismantlers.** The importance of the automotive dismantler industry should not be minimized, i.e., the first stage of the scrapped automobile’s journey. If automobiles were engineered to be dismantled efficiently and economically with low labor effort, the recovery of the valuable plastic components would be considerably enhanced. Although the automotive dismantler primarily seeks to recover parts for resale to the secondary automotive market, the dismantler’s function could be extended to the recovery of “pure” plastic components for primary recycling. This early recapture of “pure” plastic is obviously much to be preferred over the post separation of commingled plastic scrap as in ASR.

Many in the industry believe modularization will be spurred by the growing pressure to design vehicles with materials recovery in mind. Modular design by consolidating the responsibility for material selection, will promote the use of plastics that are not only recyclable, but also are compatible in mixtures. And, naturally, by concentrating the components into removable units, such structures will increase the recapture rate and save time in recovering the plastics when the car is scrapped.

### 4.3 ASR separation techniques

The goal of the Argonne National Laboratory (ANL) research program was to address the problems associated with ASR disposal costs with a view toward sustaining the economic viability of the automobile shredder industry as a major supplier of ferrous scrap to the domestic iron and steel industry. Toward that end, efforts were directed toward reducing the volume of ASR that needed to be disposed of. A corollary of that effort was to recover certain target thermoplastics from ASR in sufficiently pure form that they would have primary or secondary recycle value as an offset to the residual ASR disposal costs. These target plastics included ABS (acrylonitrile-butadiene styrene), PVC (polyvinyl chloride), PE (polyethylene) and PP (polypropylene). It also was obvious that a major volume and weight component of ASR that might most easily be removed would be the polyurethane foam (PUF). Ready markets already exist for clean scrap PUF, mainly as a carpet underlay.

The ASR that was used in this study was available from a local Chicago area major automobile shredding operation and, therefore, is the actual problem material rather than a “synthesized” composite.

**Apparatus and Procedure.** For the physical separation of ASR into recoverable segments, an apparatus was devised consisting of a multideck vibrating screen separator. A vacuum chamber was connected to the ends of the screens carrying products other than fines (see Fig. 4.2).
Experiments conducted with various size screens resulted in division of the ASR into three product streams: (1) > 1 in, Polyurethane foam (PUF); (2) 1 inch to 1/4 inch, plastic rich stream (PRS), and (3) ≤ 1/4 inch fines-glass sand, dirt, etc.

Solvent extraction was done on the plastics rich stream. Solvents used included acetone, xylene, and ethylene dichloride (EDC). A typical ASR separation run is outlined below.

An initial charge of 2968 g of raw ASR was broken down by the vibrating screen separator into three fractions.

A) PUF (contaminated with oil) 275 g
B) PLASTICS Rich Stream (PRS) 1906 g
C) Fines 787 g

Fraction A, the polyurethane foam chunks > 1 inch, was severely contaminated with residual oils. A simple acetone wash removed most of the impregnating oils. The ultimate cleanliness for the PUF was realized with a water detergent wash, which released entrapped granular dirt and sediment. The initial contaminated PUF lost 35% of its original weight. Final yield of clean PUF was 178 g or 6% of the original ASR weight.

Fraction B, the plastics rich stream, was first extracted with acetone at room temperature to remove oils, greases and mastics. The acetone washed residue was subjected to boiling EDC. The EDC soluble thermoplastics were recovered by solvent evaporation to give a tough rubbery black film. Analysis of this film by infrared spectrum, by comparison with a synthetic blend of PVC and ABS, showed it to be mainly a 50/50 blend of ABS and PVC, contaminated however with some ester functionality (acrylic polymers?). The total weight of PVC/ABS amounted to 180 g or 6% of the original ASR weight.

The residual solids after the EDC extraction were subjected to hot xylene solution, followed by cooling, resulted in the separation of a light gray granular sediment. Filtration and drying of that precipitate followed by infrared (IR) characterization revealed it to be a high purity polypropylene (PP) combined with low levels of PE. This PP fraction amounted to 54.5 g, or 1.8% of the total ASR.

Fraction C, the fines fraction, showed negligible soluble plastics content, but interestingly showed a high magnetic fines content (about 40% by weight). These magnetic fines, probably iron and iron oxides, could be an additional valuable adjunct for value recovery from ASR.

Throughout these studies of solvent separation, recovery of solvents, even though incomplete, consistently was greater than 90%. With commercially available large-scale equipment, recoveries of solvent in excess of 95% would be expected.

![Fig. 4.2 ASR Separation System](image)
4.4 Compatibilization of mixed plastics

Although it does not appear likely (but not impossible) that pure monolithic thermoplastics will be realized by solvent extraction techniques, the recovery of blends of normally incompatible plastics could be upgraded in physical properties by newly emerging compatibilization techniques.

Some of these approaches are given below:
- Flash evaporation of solvent from a solution containing two normally incompatible plastics, resulting in avoidance of gross phase separation believed responsible for major physical property deterioration (7).
- The generic use of a third compatibilizing plastic, e.g., chlorinated polyethylene (CPE), to improve the compatibility of mixtures of PE and PVC (8).
- The use of an ultrafine particle size silane coated talc with mixtures of polyethilene terephthalate (PET) and HDPE to achieve noticeably finer microstructures and better dispersion within the continous phase (10).

Such compatibilizing treatments and related technologies will become increasingly important as blends of normally incompatible plastics become increasingly available from recycling efforts.
Chapter 5
The Processing of Non-Magnetic Fractions from Shredded Automobile Scrap

5.1 Introduction

Scrapped automobile vehicles are an important source of metallic and non-metallic components. The recycling potential depends on the scrap rate (obsolescence) of cars and the value of the scrap derived from them. If the value derived is too low, obsolete cars will be abandoned (dumped) rather than salvaged.

The composition of middle-class cars is given in Tab. 5.1.

According to the first patent issued for car shredding (to Newell in 1960), a scrapped car is reduced to pieces of 150 mm or less, in a special hammer mill. The density of shredder scrap ranges from 1.2 to 1.8 Mg/m³ (last value after removing non-metals).

Downstream units are generally added to a shredder plant: first for separating non-metals and second non-ferrous metals by means of magnetic separation. The remaining magnetic fraction, which generally amounts 2/3 to 3/4 of the input, is saleable as scrap. The remaining non-magnetic fraction contains most of the non-ferrous metals (Rousseau and Melin, 1989).

Tab. 5.1 Composition of European middle-class cars (1.2-1.5 L motors)

<table>
<thead>
<tr>
<th>Range for different European cars (weight %)</th>
<th>Future average European car (weight %)</th>
<th>In USA 1980 (weight %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>57.0-76.5</td>
<td>59.7</td>
</tr>
<tr>
<td>Cast iron</td>
<td></td>
<td>7.9-13.6</td>
</tr>
<tr>
<td>Aluminium</td>
<td>2.0-10.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Copper and alloys</td>
<td>1.0-2.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Lead</td>
<td>1.1-1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.4-0.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Tin</td>
<td>up to 0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Plastics</td>
<td>1.2-12.6</td>
<td>6.7</td>
</tr>
<tr>
<td>Rubber, Glass, etc.</td>
<td>balance</td>
<td>11.8</td>
</tr>
<tr>
<td>Total weight (kg/car)</td>
<td>700-1350</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1140-1280</td>
</tr>
</tbody>
</table>

*a Of which rubber = 5.1%; paper; fabric = 10.0-10.9%*

5.2 Processing of non-magnetic fractions

5.2.1 Generalities

Typical compositions of non-magnetic fractions are given in Tab. 5.2. Formerly, non-ferrous metals were sorted by handpicking from shredder scrap. Nowadays, the integration of additional separation steps for non-metals into shredder plants allows higher metal recoveries and concentrations of magnetic and non-magnetic metals.
Intensive research on all these steps had been done in the beginning of the seventies, especially by the U.S. Bureau of Mines (see Tab. 5.3 and Fig. 5.1).

The non-magnetic fractions of numerous shredder plants have to be treated in “separation centers” (actually two centers for 34 shredder plants in West Germany).

The non-magnetic fractions contain constituents which have to be removed separately as far as possible: iron, stainless steel, aluminium, copper, lead, zinc and non-metals (rubber, plastics, glass, paper).

The remaining non-metals have to be separated in a preliminary step by using vibrating or rotating screens, by bar-sizers followed by normal screen decks, or by bar sizers only (self-vibrating or

---

**Tab. 5.2 Typical composition on non-magnetic fraction (in weight %)**

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Ref. 1</th>
<th>Ref. 2</th>
<th>Ref. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>2-4</td>
<td>5-10</td>
<td></td>
</tr>
<tr>
<td>(incl. brass)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>1-2</td>
<td>&lt; 1</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>6-15</td>
<td>12-15</td>
<td>20-25</td>
</tr>
<tr>
<td>(incl. Mg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stainless steel</td>
<td>0.1-0.2</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>1-4</td>
<td>35-40</td>
<td>30-40</td>
</tr>
<tr>
<td>Iron</td>
<td>6-16</td>
<td>n.a.</td>
<td>10</td>
</tr>
<tr>
<td>(of which 75% as metal)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubber, Plastics</td>
<td>20-25</td>
<td>n.a.</td>
<td>20-30</td>
</tr>
<tr>
<td>Glass and non-combustible</td>
<td>35-50</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Dirt, dust</td>
<td>n.a.</td>
<td>n.a.</td>
<td>5-10</td>
</tr>
</tbody>
</table>

1 Without previous separation of non-metals
2 After separation step for non-metals (principally air separation)
3 After screening

**Tab. 5.3 USBM Process for treatment of non-magnetic fractions**

<table>
<thead>
<tr>
<th>Process Step</th>
<th>Composition (%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cu</td>
<td>Zn</td>
</tr>
<tr>
<td>Air classification</td>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>Screen 4 mesh (= 4.7 mm)</td>
<td>6</td>
<td>33</td>
</tr>
<tr>
<td>Water elutriation</td>
<td>6</td>
<td>43</td>
</tr>
<tr>
<td>Magnetic separation</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Non-magnetic fraction</td>
<td>9</td>
<td>71</td>
</tr>
<tr>
<td>Hand picking</td>
<td>80</td>
<td>n.a.</td>
</tr>
<tr>
<td>Heavy-medium separation</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Al-fraction</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>heavy metal (die cast)</td>
<td>2</td>
<td>88</td>
</tr>
<tr>
<td>Overall recovery in heavy metal fractions</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Overall metal recovery</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1 For composition of non-magnetic fraction (after partial cannibalisation of cars) see Table 5.2
2 With only less than 1% of non-metals in this fraction
3 With galena water slurry (specific gravity of 3)
4 Stainless steel is recovered to about 100%, up to 99% are recovered in the magnetic fractions
5 Including stainless steel (less than 1%)
6 Stainless steel
vibrosizers).

Rising current separators can be employed to remove non-metals by first liberating them and then floating them off. The utilisation of a rotary drum air classifier was proposed.

The application of jigs is limited as they can be used for fine fractions only, and they require a large quantity of water.

5.2.2. Industrial methods for non-ferrous metals recovery

Different methods applicable are listed in Tab. 5.4 and 5.5. These beneficiation methods produce intermediate fractions but normally do not succeed in selective enrichment of each non-ferrous metal in a particular product. These fractions are generally treated pyrometallurgically in order to enrich each non-ferrous metal in a specific phase.

The first enrichment steps of non-magnetic fractions are generally based on dense-medium separation for which sink-float processes predominate. In the past fluidized beds and pneumatically pinched sluices were proposed.

The dense medium separation is sufficient to separate light (Al, Mg) from heavy metals (Cu, Zn, Pb). The classical sink-float process is often not used for economic reasons. The latest developments use drum separators. They are shown in Fig. 5.2. A three-products drum separator for example comprises one low-gravity and one high-gravity separate compartment. Float material overflows at one end of the drum. A revolving lifter removes continuously each sink product of each compartment. Drum separators admit pieces of 6-150 mm and produce fractions with metal contents of 85-90%.

The efficiency of hydrocyclone separation can be increased by the use of heavy media, but the granulometry of the feed is limited up to 50 mm, e.g. 15 mm. Thus, the treatment of non-magnetic fractions requires previous screening (see below). Hydrocyclones can be used for separation of non-metals.

After removal of non-metals, the non-ferrous metals have to be enriched in different fractions. This can occur by taking advantage of their different melting points.

**Fig. 5.1 Flow-sheet and material balance (based on 27.2 Mg of non-magnetic reject per day) pf U.S.B.M. Process**
Special furnaces were developed for this purpose, such as the Coreco furnace which can process various types of scrap. It consists of a rotary kiln externally heated, equipped with an inner perforated scrap container. The oxidation of even finely divided scrap is minimized by a multi-zone temperature control. The processing of the sink-float fraction leads generally to the production of zinc fraction, lead dross and brass fraction.

Similarly the TS-process (Trennschmelz-Verfahren) was developed for easy treatment of fractions even under 15 mm with separation into highly concentrated metal fractions. For example copper-rich (45-50% Cu), zinc-rich (92% Zn) and lead-rich (90% Pb) products are obtained after a two-stage TS-treatment. The metal extraction takes to be extracted. Consequently, only one metal, or alloyed metal, can be recovered in one step. The energy requirement for two-step work, amounts to about 2.1 GJ/Mg of non-magnetic feed. Other processes based on similar features are under development.

<table>
<thead>
<tr>
<th>Tab. 5.4 Process for separation of metals and non-metals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Separation criterion</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Density properties</strong></td>
</tr>
<tr>
<td>Dry processes</td>
</tr>
<tr>
<td>sieving</td>
</tr>
<tr>
<td>air classification</td>
</tr>
<tr>
<td>fluized bed</td>
</tr>
<tr>
<td>air jug</td>
</tr>
<tr>
<td>cyclone</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>Wet processes</td>
</tr>
<tr>
<td>current separation</td>
</tr>
<tr>
<td>shaking</td>
</tr>
<tr>
<td>table</td>
</tr>
<tr>
<td>jig</td>
</tr>
<tr>
<td>dense medium separation</td>
</tr>
<tr>
<td>cyclone</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>Optical properties</td>
</tr>
<tr>
<td>automatic sorting</td>
</tr>
<tr>
<td>Electrical properties</td>
</tr>
<tr>
<td>high voltage separation</td>
</tr>
<tr>
<td>Magnetic properties</td>
</tr>
<tr>
<td>low magnetic field</td>
</tr>
<tr>
<td>high magnetic field</td>
</tr>
<tr>
<td>eddy-current repulsion</td>
</tr>
<tr>
<td>techniques</td>
</tr>
<tr>
<td>Hydrophobic properties</td>
</tr>
<tr>
<td>flotation</td>
</tr>
<tr>
<td>Thermal properties</td>
</tr>
<tr>
<td>mechanical system</td>
</tr>
</tbody>
</table>

Special furnaces were developed for this purpose, such as the Coreco furnace which can process various types of scrap. It consists of a rotary kiln externally heated, equipped with an inner perforated scrap container. The oxidation of even finely divided scrap is minimized by a multi-zone temperature control. The processing of the sink-float fraction leads generally to the production of zinc fraction, lead dross and brass fraction.

Similarly the TS-process (Trennschmelz-Verfahren) was developed for easy treatment of fractions even under 15 mm with separation into highly concentrated metal fractions. For example copper-rich (45-50% Cu), zinc-rich (92% Zn) and lead-rich (90% Pb) products are obtained after a two-stage TS-treatment. The metal extraction takes to be extracted. Consequently, only one metal, or alloyed metal, can be recovered in one step. The energy requirement for two-step work, amounts to about 2.1 GJ/Mg of non-magnetic feed. Other processes based on similar features are under development.
Tab. 5.5 Process for separation of components of shredder scrap

<table>
<thead>
<tr>
<th>Components to be separated</th>
<th>non-metal/ metal</th>
<th>light metal/ heavy metal</th>
<th>heavy metal heavy metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity separation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sink-float</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>hydroclassification (Jig)</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>air classification</td>
<td>X</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>hydrocyclone</td>
<td>X</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>sluice and table</td>
<td>X/+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rising current separator</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetic field separation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low intensity</td>
<td>X(^\d)</td>
<td>X(^\d)</td>
<td>X(^\d)</td>
</tr>
<tr>
<td>high intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>eddy current repulsion</td>
<td>X/+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>para-magnetic liquid separation</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Eletric field separation</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flotation</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic sorting</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Selective grinding(^b)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring process(^c)</td>
<td></td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>

\(^a\) If at least one metal has magnetic properties
\(^b\) Possible after cryogenic treatment
\(^c\) Related to elasticity behaviour

“X”: developed on an industrial scale; “+”: not developed industrially or only single case

5.2.3 New processes and developments
The dense medium separation can be improved by using the fact that non-magnetic material in a non-homogeneous magnetic field can be separated in sink and float products. The feed granulometry must range normally from +0.1 mm, to -10/-30 mm. Pilot Plants of a capacity of 0.3 to 1.5 Mg/h are known in Czechoslovakia, U.K., Japan, USSR, Israel and U.S.A.

![Three-products drum separator](image-url)
Pilot tests were made in Japan for non-magnetic fractions having a granulometry of 6 to 25 mm (max. 30 mm). The pilot plant includes two magnetic separation cells (see Fig. 5.3 and 5.4), one for the separation of aluminium, the other one for the separation of copper, zinc and lead from each other. The first cell operates at an apparent density of 2.3-5.6, the second of 4.3-10.8.

The recovery of aluminium was 80%, the losses of ferro-fluid less than 0.1%.

Various ore-sorters can be considered for the use of scrap classification:
- Photometric sorters: handle sizes from 10 to 120 mm
- Conducting/magnetic sorters: handle sizes from 25 to 150 mm
- Electrostatic sorters: handle sizes from 0.1 to 25 mm. These sorters are used for example for separation of chopped wire from plastics
- Radiometric sorters: combination of material irradiation and measurement of scattered gamma-radiation.

The ore sorters are mostly expensive and apply to high throughputs. The major problem consists in presenting the individual lumps before the sensing system.

The ECR-process (eddy-current repulsion) allows the separation of components with low differences in density (e.g. copper and lead, stainless steel). The repulsive force set-up by eddy current depends on the ratio of electrical conductivity to specific weight (see Table 5.6), and in practice, depends additionally on particle sizes and shapes.

The required magnetic field can be

---

*Fig. 5.3 Schematic representation of a separation cell*

*Fig. 5.4 Distribution of levitation force in the cross and longitudinal section in separation cell*
- variable: a pilot plant of propulsor type is shown in Fig. 5.5
- stationary: the scheme of vertical ECR-separator is shown in Fig. 5.6 and test results in Table 5.7.

Tab. 5.6 Parameters for components separation of non-magnetic fractions

<table>
<thead>
<tr>
<th>Component</th>
<th>(1) Specific gravity (Mg/m³)</th>
<th>(2) Specific electrical conductivity (1/mΩ)</th>
<th>(2)/(1) ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>2.7</td>
<td>36.5x10⁶</td>
<td>13.5x10⁶</td>
</tr>
<tr>
<td>Copper</td>
<td>8.9</td>
<td>58.0x10⁶</td>
<td>6.5x10⁶</td>
</tr>
<tr>
<td>Zinc</td>
<td>7.1</td>
<td>18.2x10⁶</td>
<td>2.6x10⁶</td>
</tr>
<tr>
<td>Brass</td>
<td>8.4</td>
<td>15.0-26.0x10⁶</td>
<td>1.8-3.1x10⁶</td>
</tr>
<tr>
<td>Lead</td>
<td>11.3</td>
<td>4.8x10⁶</td>
<td>0.4x10⁶</td>
</tr>
<tr>
<td>Tin</td>
<td>7.3</td>
<td>7.7x10⁶</td>
<td>1.1x10⁶</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1.7</td>
<td>23.0x10⁶</td>
<td>13.5x10⁶</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>7.7-7.8</td>
<td>1.4-2.0x10⁶</td>
<td>0.2-0.3x10⁶</td>
</tr>
<tr>
<td>Glass</td>
<td>2.3-3.6</td>
<td>10⁻²⁻¹⁰⁻⁺</td>
<td>nil</td>
</tr>
<tr>
<td>Plastic</td>
<td>1.0-2.0</td>
<td>2.0⁻¹⁻¹⁰⁻⁺</td>
<td>nil</td>
</tr>
<tr>
<td>Rubber</td>
<td>1.0-2.0</td>
<td>10⁻¹⁻¹⁰⁻⁺</td>
<td>nil</td>
</tr>
</tbody>
</table>

The major problem of ECR separation is to present each particle feed individually to the system.
5.3 Industrial applications

An efficient recycling is based on an interconnection of shredder units, separation centers and metal producers, as described below.

Tab. 5.7 Test results with vertical ECR-separator

<table>
<thead>
<tr>
<th>Fraction to be treated</th>
<th>Input (%)</th>
<th>Fraction content (%)</th>
<th>Recovery (%)</th>
<th>Residue content (%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-metal/magnesium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td>53.0</td>
<td>93.4</td>
<td>91.7</td>
<td>9.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Rubber and others</td>
<td>47.0</td>
<td>6.6</td>
<td>7.6</td>
<td>90.5</td>
<td>92.5</td>
</tr>
<tr>
<td>Light metal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium, glass</td>
<td>62.0</td>
<td>98.0</td>
<td>90.0</td>
<td>12.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Stone</td>
<td>35.0</td>
<td>1.30</td>
<td>3.0</td>
<td>84.0</td>
<td>97.0</td>
</tr>
<tr>
<td>Insulated copper wire</td>
<td>3.0</td>
<td>0.7</td>
<td>15.0</td>
<td>4.0</td>
<td>85.0</td>
</tr>
</tbody>
</table>

Tests made in connection with fraction output of DSM-process
Enriched before treatment by screening (overflow containing rubber, plastics, misc. non-magnetic parts)

Tab. 5.8 Plant performance of SMA

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Weight (%)</th>
<th>Sn</th>
<th>Fe</th>
<th>Cu</th>
<th>Ni</th>
<th>Cd</th>
<th>Ag</th>
<th>Sb</th>
<th>Zn</th>
<th>Pb</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td>100</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Cu-bearing product</td>
<td>57</td>
<td>n.a.</td>
<td>n.a.</td>
<td>46.3</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Lead product</td>
<td>9</td>
<td>6.05</td>
<td>0.001</td>
<td>0.04</td>
<td>0.001</td>
<td>0.013</td>
<td>4.01</td>
<td>0.002</td>
<td>bal.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Zinc product</td>
<td>27</td>
<td>0.19</td>
<td>0.008</td>
<td>2.3</td>
<td>0.013</td>
<td>0.003</td>
<td>n.a.</td>
<td>n.a.</td>
<td>bal.</td>
<td>0.65</td>
<td>4.4</td>
</tr>
<tr>
<td>Dust/dross</td>
<td>7</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>42.0</td>
<td>38.3</td>
</tr>
</tbody>
</table>

5.3 Industrial applications

An efficient recycling is based on an interconnection of shredder units, separation centers and metal producers, as described below.

Fig. 5.6 Scheme of vertical ECR-separator
5.3.1 Shredder units and separation centers

The scheme of a shredder plant at Duisburg, West Germany, is shown in Fig. 5.7. The non-magnetic fraction (50% metal content) is hand-picked, and the remaining fraction is screened at 8 mm. The + 8 mm is sent to the sink-float plant of Metal Float GmbH. Fines are sent directly to the SMA-plant (described below).

Fig. 5.7 Scheme of typical shredder plant (Duisburg)

Fig. 5.8 Scheme of SMA-plant
Fig. 5.9 Flow sheet of shredder scrap processing

Fig. 5.10 Scheme of a Coreco furnace

2 Replace containers of separated metals as they are filled

1 Load raw material continuously into charge end
The throughput of Metal Float GmbH amounts to 2-4 Mg/h. Ferro-silicon is used as heavy medium in a two-products frum separator.

The flow-sheet of the SMA-plant is given in Fig. 8. The plant was started in 1981. The total ca-

![Material balance of a Coreco furnace (Trennschmelz GmbH)](image)

**Fig. 5.11 Material balance of a Coreco furnace (Trennschmelz GmbH)**

![Flow-sheet of a metallurgical plant ("Berzelius", Duisburg)](image)

**Fig. 5.12 Flow-sheet of a metallurgical plant ("Berzelius", Duisburg)**
Capacity amounts to 1.0–1.5 Mg/h, the melting capacity to 0.5–0.8 Mg/h. The Al-fraction is ground in an impact breaker for separation of stone and glass (up to 40% in weight). The purified Al-scrap is melted. The heavy metal fraction is sent for processing into the two TS-units. The plant performances are summarized in Tab. 5.8.

5.3.2 Separation centers and non-ferrous metals producers

Fig. 5.9 shows the sink-float plant of Eumet GmbH at Frankfurt, West Germany. The plant has a capacity of up to 25 Mg/h.

The heavy medium is up to 65 mesh (=0.21 mm). Fe-Si losses amount to ca. 4-5 kg per Mg of feed. The metal recovery is ca. 95%. The separation takes place in two steps in a drum separator:
- separation of rubber and magnesium at 2.2 Mg/m³. The rubber fraction is normally dumped but some cement plants are able to use it as fuel
- separation of aluminium at 3.4 Mg/m³.

The fines of the non-magnetic fractions can be processed in a special way for recovery of non-ferrous metals (Pb, Cu, Ag) instead of dumping, e.g. applying shaking tables, jigs, etc.

The heavy metal fraction is sent to Trennschmelz GmbH at Duisburg, West Germany. The plant has a capacity of up to 2.2 Mg/h.

A furnace scheme is shown in Fig. 5.10. Material balance and analysis are given in Fig. 5.11 for an exemplary 2 Mg charge of the heavy fraction. The lead and zinc fractions are recycled to the lead-zinc plant of Berzelius GmbH, Duisburg as shown in Fig. 5.12.

5.3.3 Shredder and non-ferrous metal producers

Metallhüttenwerke Bruch KG, Dortmund, West Germany, treated shredded scrap, especially for recovery of aluminium, from shredded scrap (av. -60 mm, max. 100 mm) as shown in Fig. 5.13. The heavy media process was performed in two steps:
- separation of non-metals and magnesium at 2.5 Mg/m³
- separation of aluminium at 2.9 Mg/m³.

The remelting of aluminium fraction occurs basically as shown in Fig. 5.14.

5.3.4 Hydrocyclone classification of shredded scrap

Since 1977 Dalmeijers Metalen B.V., Rotterdam, Netherlands, uses DSM-hydrocyclones. The flow sheet is shown in Fig. 5.15 and the production data are listed in Tab. 5.9. The feed (6.5 Mg/h) has to be screened at 50 mm prior to hydrocycloning. The main non-metals are first separated. The sink fraction is dewatered on a vibrating sieve and mixed with the heavy medium (magnetite with some Fe-Si) at a density of 2.3 Mg/m³. Non-metals and magnesium are separated before by hydrocycloning in a dense medium tank using this medium. Afterwards, light metals are separated from heavy metals in dense medium hydrocyclones.

The same company envisages the utilisation of the ECR-process for further processing of the different fractions.

By comparison, the plant of Reynolds MEtals Co. (Sheffield, Ala., USA), started in 1981, is based on similar processing features with hydrocyclones, as shown in Fig. 5.16.

5.4 Review on the recovery of non-ferrous metals

Aluminium

The recovery and reuse of aluminium results in considerable energy savings. This has to be related to the fact that about 27% of Al-production are scrap-based. The recovered aluminium can be used economically for alloying purposes or can be refined. Some plant problems were reported with regard to the purity of remelted aluminium.
Fig. 5.13 Flow-sheet for processing of shredded aluminium

Fig. 5.14 Operational scheme of a melting process in a secondary aluminium smelter
Fig. 5.15 Typical flow-sheet for hydrocycloning of non magnetic fraction (DSM-Process)

Product AII: rubber, plastics, magnesium and other light materials
Product B: aluminium
Product C: heavy non-ferrous metals (copper, lead, zinc, brass)

Fig. 5.16 Flow-sheet of Reynolds Metals
Zinc

Zinc is generally recovered in metallic form, a small proportion in the form of oxides which are recovered by means of pyrometallurgical processes, especially by shaft furnace smelting.

Lead

Lead recycling amounts to about 40% of the total consumption worldwide, mostly in form of old scrap. Lead from wrecked cars is recovered in two different ways. The most important consists of battery removal prior to car shredding.

Lead contained in non-magnetic fraction is normally highly contaminated with zinc. The metal contents can be recovered separately or together in a lead-zinc processing plant in the way previously described.

Copper

Copper recycling amounts to about 30-35% of the production.

Copper and copper-bearing materials from different sources can be treated together in a shaft furnace and/or converter.

Tin

The quantity of tin in shredder scrap is low. As contamination of iron-bearing material with tin is to be avoided, tin has to be recovered together with lead.

5.5 Conclusions

Reclaimed material from wrecked cars is a growing source of non-ferrous metals. A shredder plant produces non-magnetic fraction in a fairly low quantity. Only a “separation center” collecting the non-magnetic fractions from about 15 to 20 shredder plants can work economically. This must be closely linked to an effectively organised scrap centralisation and processing as well as to the sort of infrastructure which is existing in industrialised areas. These logistics play an important role with regard to an efficient collection of NF-metals.

The further processing of non-magnetic fraction decreases the quantity of disposed material and its contamination by heavy metals.

The recovery of non-ferrous metals takes place under controlled conditions and in industrial plants. The energy requirements for non-ferrous metals production can be lowered considerably, if scrap is utilized.

The customary processes include the following steps:
- separation of residual non-metals: generally by screening
- separation of light and heavy metals: using difference in density e.g. sink-float separation or hy-

---

### Tab. 5.9 Hydrocycloning of non-magnetic fraction of shredded scrap

<table>
<thead>
<tr>
<th>Specific gravity (Mg/m³)</th>
<th>Input (weight %)</th>
<th>Fractions (weight %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-metal magnesium</td>
<td>Light metals</td>
</tr>
<tr>
<td>&lt; 1.8</td>
<td>25.8</td>
<td>83.2</td>
</tr>
<tr>
<td>1.8-2.3</td>
<td>0.9</td>
<td>5.8</td>
</tr>
<tr>
<td>2.3-3.0</td>
<td>41.0</td>
<td>10.2</td>
</tr>
<tr>
<td>&gt; 3.0</td>
<td>30.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Total (weight %)</td>
<td>100.0</td>
<td>30.0</td>
</tr>
</tbody>
</table>

---

Tab. 5.9 Hydrocycloning of non-magnetic fraction of shredded scrap
drocycloning, alternatively jigging or rising current separation

- separation of different heavy metals: by pyrometallurgy (e.g. in a rotary furnace), alternatively by means of eddy current separation process, magnetic field separation or eventually automatic sorting.

Nevertheless, no standard solution is applicable, since the composition of the non-magnetic fraction varies widely. Further, logistical problems linked to specific site conditions are of great significance. Each case has to be examined separately, especially if other types of scrap (incinerator refuse, household waste, cable scrap, etc.) are processed in the same plant.
Chapter 6
Automotive plastics recycling

6.1 Optimizing plastic parts for recycling

6.1.1 Introduction

Applications of automotive plastics to reach specific design targets date back many years, with both weight of plastics used and share of plastics in vehicle weight increasing constantly. The amount of plastics used in the automobile will continue to increase in the future, because of more demanding design concepts, new safety requirements, customer demand for increased comfort, reduced production costs, and general demand for reduced fuel consumption. The history and future projection of plastics use for one manufacturer’s models are shown in Fig. 6.1 (Automotore Engineering, 1995).

Today no other large-scale industrial product is recycled to the same extent as the automobile. Vehicle components made of plastic, to a large extent today, are used again as recycled plastics for the production of new components. As a result, specialized recycling plants are already able to reuse approximately 75% of all the materials contained in an old car. However, shredder residue consisting of plastics, rubber, glass, and upholstery, still amount to a large volume of waste to be sent to landfills.

Nearly all European automakers have been operating recycling plants to test procedures for dismantling and reconditioning. From that experience, European automakers have an industry-wide recycling concept that significantly reduces residues going to disposal sites. The initial step groups materials from old cars for the most suitable recycling methods. Scrap from production of plastic parts involves rejects, castings, stampings, and trimming flash. Recycling these plastics is particularly easy, since the materials are readily known, and contamination is low.

6.1.2 Processes for recycling plastics

In establishing plastics recycling processes, an automaker must develop not only dismantling procedures, but also an adequate number of suitable applications for using the materials recycled. The

Fig. 6.1 Plastics use in BMW cars since 1976
plastics recycled must offer a suitable price/benefit ratio versus new plastic material which might be used as an alternative. This is seen in Fig. 6.2. Recycled plastics from old vehicles have a value of $2.00/kg, see Fig. 6.3. Only 35% of the overall cost results from recompounding, while 65% of the total cost is attributable to other procedures upstream, such as dismantling, sorting, and transportation.

A cost comparison of recycled automotive plastics and new plastics shows that the cost gap narrows only at the medium price level of automotive plastics. In other words, recycling low-cost plastics is not yet economically viable because the recycling costs are too high. Cost reductions of recycled plastics will come as a result of faster dismantling and sorting, higher quality sorting, more efficient transportation, less costly separation and recompounding, use of recycled plastics at the highest possible level, and economies of scale. These reductions depend on automakers designing new models optimized for recycling.

6.1.3 Assessing recyclability

With corporate-wide standards for assessing recyclability, all vehicle components can be assigned to a recycling category, and those categories entered on design drawings. For each component, later recycling is taken into consideration from the beginning of the actual development process.

A part’s recyclability is determined using these parameters: absence of known problem materials, volume of materials gained by recycling, and the technical and economic suitability of specific materials for recycling.

![Fig. 6.2 Price/benefit ratio of recycled plastics](image1)

![Fig. 6.3 Cost structure of recycled automotive plastics](image2)
Using the design drawings throughout the development process can reveal and support actions to improve recyclability. In this way, all departments and development engineers are forced to carry out activities promoting recycling.

Analysis of plastics in cars older than 15 years shows that only a few of the plastics used then can be recycled even with some difficulty. In comparison, measures taken to optimize recycling are paying off now since a much larger share of the plastics used on modern cars are recyclable by the same criteria.

It would also be fair to ask whether recycling should take priority over selecting the most suitable materials and production techniques. By virtue of their performance and design potential, these materials make active contributions towards the more economic use of natural resources, e.g. by saving energy. However, sandwich structures represent a case in point to demonstrate that the most suitable materials need not necessarily permit ready recycling (Weber, 1990).

Under this aspect, a critical light is also thrown on discussions over a ‘standard’ plastic for automobiles. In this case, the way could be prepared for a reasonable compromise, because functionality takes priority over costs and recycling in the automobile industry is giving full and active support to all measures that promote recycling, e.g. by appropriate design of composites. Thermoplastics and thermosetting plastics can be recycled and, in this respect, they do not differ from other materials used in automobile manufacture. Those concerned - i.e. the automobile industry, suppliers and raw materials manufacturers - assign first priority to recycling materials. The second place is allotted to the recovery of energy and chemical recycling, e.g. pyrolysis. The possibility of obtaining recycling quotas of 100% is just as remote for plastics as it is

6.1.4 Optimized design of components

Correct choice of materials is important for recycling-optimized design. For example, if materials have to be segregated prior to recompounding, then specific combinations of materials have a substantial effect on the segregation result and cost.

Several rules have been found desirable in choosing materials for subsequent recycling:
- limit the number of plastic used
- choose plastics according to recyclability and use of recycled material
- give preference to plastics insensitive to contamination and processing
- give preference to plastics widely compatible with other plastics
- design composite plastic structures of uniform or compatible plastics
- prohibit use of incompatible plastics, even as an alternative
- avoid surface linings, avoid plastic/metal structures
- give preference to natural reinforcement materials.

An additional set of rules applies to designing for recycling:
- mark components with materials used, according to accepted standards
- use joining methods optimized for dismantling
- mark fastening and attachment points and make them easily accessible
- design composite parts that are easy to separate when plastics are incompatible
- design plastic and metal structures that can be separated manually or by using only simple tools
- use only plastics that are common, commercially available
- give preference to design concepts using recycled plastics
- check specifications to encourage using recycled plastics
- develop repair concepts for parts susceptible to damage
- consider life-cycle analysis when choosing repair concepts.

Production methods significantly affect recyclability. For example, production adhesives can markedly reduce the properties of plastics recycled later. A third set of rules guides choices of production methods:
- avoid adhesives for joining composite components
- choose melting adhesive over solvent adhesives
- use thermal pressing for molded parts of fabric, tissue, or particles
- use hot-duct injection molding to reduce scrap volumes
- apply production methods with later recycling as a priority
- choose methods generating minimum waste
- avoid processes using materials with personal or environmental hazards.

As can be seen from Fig. 6.4, the research programme recycling plastics and disposing of shredder scrap has focused attention on individual problems.

The automotive engineering research association has commissioned a company, Dr-Ing, h. c. F. Porsche, Zuffenhausen, Stuttgart, FRG, to devise a scheme for designing automobiles that can be easily dismantled. The aim of the project was to submit suggestions for a production-line car in the medium price bracket that would allow plastic parts and assemblies to be readily dismantled and subsequently sorted into pure fractions that could be recycled (Weber, 1991).

A production-line vehicle currently on the market had to be analyzed to derive guidelines of a general nature that would lead to a design that could be readily dismantled. The vehicle studied contains 97 kg of all kinds of plastics, 63% of which could be sorted; 46% of the total, i.e. 73% of the fraction that could be sorted, was accounted for by parts that could be separately dismantled and consisted solely of a given type of thermoplastic. As was to be expected, the bumpers, polyethylene fuel tanks and polyolefin interior trim could be dismantled particularly easily and rapidly; 30% of the total could be dismantled in about 20 min. The total time required for dismantling all the plastic parts and assemblies was 74 man minutes, and another 41 man minutes were required for dismantling these parts themselves and sorting them into the individual classes. Thus the grand total was 115 man minutes. Accordingly, the time required for removing each kilogram of plastics from the vehicle was 46 s, and a total of 71 s was required for dismantling and sorting.

![Fig. 6.4 State-of-the-art for mass-produced automobile parts](image-url)
A breakdown of the thermoplastic parts and assemblies that could be dismantled within 20 min is presented in Table 6.1 and the sequence in which they were dismantled is evident from Table 6.2. The results will be published by FAT (automotive engineering research association) in the near future.

In the light of this initial analysis, the automobile and plastics industries intend to devise designs that will facilitate dismantling from combinations of materials that permit recycling. An example is a bumper system that was presented by BASF at the K89. It consists of a polypropylene sheath, an expanded polypropylene core and a glass-reinforced polypropylene beam. Basic rules for designing engineering parts that permit recycling have already been published (VDI-Richlinie 2243 E). It has also been suggested that existing West German recommendations on identifying plastics parts be revised and enlarged.

Table 6.1 Fractions of materials used to produce the assemblies that could be dismantled from a VW Passat B3 within a period of 20 min.

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>15.4</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>8.7</td>
</tr>
<tr>
<td>ABS/ASA</td>
<td>5.4</td>
</tr>
<tr>
<td>Polyoxymethylene</td>
<td>0.4</td>
</tr>
<tr>
<td>Polyamide</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 6.2 Suggested sequence for dismantling the various assemblies

<table>
<thead>
<tr>
<th>No.</th>
<th>Part or assembly</th>
<th>Cumulative time for dismantling and taking a part (s)</th>
<th>Cumulative mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front bumper</td>
<td>90</td>
<td>5.598</td>
</tr>
<tr>
<td>2</td>
<td>Rocker panel</td>
<td>120</td>
<td>6.692</td>
</tr>
<tr>
<td>3</td>
<td>Rear bumper</td>
<td>270</td>
<td>12.370</td>
</tr>
<tr>
<td>4</td>
<td>Map pocket on front door</td>
<td>330</td>
<td>14.272</td>
</tr>
<tr>
<td>5</td>
<td>Sidewipe strip</td>
<td>410</td>
<td>16.156</td>
</tr>
<tr>
<td>6</td>
<td>Fuel tank</td>
<td>830</td>
<td>24.675</td>
</tr>
<tr>
<td>7</td>
<td>Rear shield</td>
<td>860</td>
<td>25.244</td>
</tr>
<tr>
<td>8</td>
<td>Door window seal</td>
<td>900</td>
<td>25.956</td>
</tr>
<tr>
<td>9</td>
<td>Tool box</td>
<td>910</td>
<td>26.128</td>
</tr>
<tr>
<td>10</td>
<td>Roof lining</td>
<td>920</td>
<td>26.298</td>
</tr>
<tr>
<td>11</td>
<td>Air filter</td>
<td>1010</td>
<td>27.725</td>
</tr>
<tr>
<td>12</td>
<td>Cover for windscreen wiper linkage</td>
<td>1020</td>
<td>27.860</td>
</tr>
<tr>
<td>13</td>
<td>Expansion tank for cooling water</td>
<td>1060</td>
<td>28.374</td>
</tr>
<tr>
<td>14</td>
<td>Front wheel arch shell</td>
<td>1180</td>
<td>29.844</td>
</tr>
<tr>
<td>15</td>
<td>Radiator cover</td>
<td>1195</td>
<td>30.017</td>
</tr>
</tbody>
</table>

In many cases, the concept of automobiles designed to facilitate dismantling conflicts with the principle of light and composite structures. The question also arises whether it would be in the interests of technological progress and the human race in general to design a highly sophisticated product, the automobile, not from the point of its optimum use but from the aspect of optimum recycling of its individual parts. It would appear worthwhile to find a sound compromise with the aim of restricting dismantling to assemblies that are readily accessible in any case. A realistic basis would be to recover and recycle about 30% of the plastics used in automobiles. Weight-saving necessitates anisotropic structures of great strength, as can be realized by adopting the principles of lightweight construction, and effectively contributes towards the economics of automotive engineering and pro-
tection of the environment. However, light structures need not necessarily be easy to dismantle. In fact, sandwich structures and highly integrated assemblies point to the opposite. A reliable ecological balance ought to be struck between the energy that can be saved by weight-saving and that which can be achieved by recycling the materials. The plastics used in automobiles can be broken down into a few predominant types. Polyolefins hold out the best prospects for recycling. This fact leads to the demand that the plastics used in automobiles should be restricted to 10 classical types. However, the parts in the engine compartment, assemblies, electronic units and other highly technical parts cannot all be classified in this category (Steirle, 1989).

6.1.5 Reuse of worn parts
The second circuit in Fig. 6.4 concerns the reuse of worn parts, which is an established tradition in automotive engineering and is carried out on an industrial scale. Ever since motor vehicles have existed, replacements have been offered for engines, transmission systems, axles and electrical equipment. Engines reconditioned by the manufacturer are encountered in everyday practice. Replacements for plastic parts are also quite common. Big scrap dealers, e.g. Kisow in Norderstedt, offer facilities for dismantling plastics bumpers and other parts or assemblies in order to gain spare parts (Wutz, 1998).

6.1.6 Recycling plastics removed from abandoned vehicles
Regrinding pure sorts of plastic scrap. Plastic scrap that is intended to be recycled must be reduced in size. If necessary, it has to be sorted beforehand and impurities have to be removed before it can be sold. The secondary market for regrind is well established and is in the hands of private dealers. Clean regrind consisting of only one type of plastic can bring prices of up to 70% of the virgin quality.

In 1988, 9.2 million tonnes of plastics were produced in West Germany, and the corresponding figure for plastic scrap was about 2.5 million tonnes, of which about 500,000 tonnes was recycled by about 200 companies. This figure includes the clean scrap recovered from automobiles. No figures are available for the amounts of material recycled by processors.

Four major West German chemical manufacturers have investigated the possibility of finding applications for this secondary material. Means have been sought for recycling high-molecular-weight polyethylene bumpers (Hoechst AG, Frankfurt, FRG), polypropylene battery casings and tanks for windscreen wash assemblies (Chemische Werke Hüls AG, Marl, FRG), and glass-reinforced nylon and ABS wheel hub caps (Bayer AG, Leverkusen, FRG). The studies are to be extended to include other large plastic parts.

The first results in the studies on the individual recycling projects are now available. Differences were revealed in the ease with which the individual plastics could be recovered. Plastic fuel tanks, all of which were unfluorinated and 10 years old, presented difficulties because of the petrol that they had absorbed. They thus had to be degassed beforehand. The main difficulty presented by the wheel caps was the paint, and a large outlay on cleaning was required for the bumpers. Batteries presented the least problems.

It is thus already apparent that the economic aspects of recycling can by no means be left out of consideration and that recycling at any price is no solution to the problem. On the other hand, no difficulties exist in processing the secondary material. No deterioration in quality was observed in processing the regrind obtained from plastic fuel tanks: even the mechanical properties were not impaired. The strength of articles obtained from recycled wheel caps was 90-95% of that achieved with the virgin material.

Volkswagen are erecting a plant in Leer, in which experiments will be performed in recycling readily accessible parts of scrapped vehicles; e.g. bumpers, fuel tanks, and trim. The installation includes a shredder. BMW are pursuing activities of this nature in Wackersdorf, and other concerns are
preparing similar projects.

The studies embrace dismantling techniques, the outlay on cleaning, and size reduction and sorting procedures. Information must be obtained on the attainable properties of the recovered material and, in particular, on the means of processing it.

The long-term targets are closed circuits; for instance, a fuel tank should become a fuel tank again by the techniques described. Obviously, this does not succeed in all cases.

Recycling quotas of 30% are aimed at, and recycling of materials and energy must go hand-in-hand.

Since the recovered material must satisfy quality specifications, in conformace with standard practice in the automobile industry, the product streams of recycled material must be kept under strict control by the automobile manufacturer.

Close cooperation in these experiments is maintained between automobile manufacturers and the plastics industry, i.e. between the processors and the raw materials manufacturers. However, the infrastructure is undoubtedly the crucial factor in recycling materials. It already commences in channeling the abandoned vehicles to the scrap heap and separating them according to their make and model.

Plans entertained by German chemical concerns on a joint venture for recycling plastics waste are in the same direction but transgress the limits set by the recovery of plastics from abandoned vehicles. Several companies have established central service departments dealing with plastics and the environment. The task of these departments is to devise solutions for disposing of and recycling plastics waste and to realize pilot projects. The most difficult task in this connection is again presented by the logistics, i.e. the planned collection of plastics waste and sorting it into the various types. A new field of activity has thus been opened up.

6.1.7 Recycling-optimized parts

Complex designs of rear light clusters using several different materials follow from specific functional, styling, and legal requirements, described in Fig. 6.5. Polymethyl methacrylate (PMMA) plastic for the lenses is a fundamental design requirement for this application. Another requirement for high-temperature resistance limits the number of suitable plastics. The joining technologies for rear-light clusters include welding, gluing, bolting, riveting, soldering, clamping, and flanging, in addition

![Fig. 6.5 Concept of typical recycling-optimized rear light cluster](image)

<table>
<thead>
<tr>
<th>Existing part</th>
<th>Optimized part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer lens</td>
<td>PMMA</td>
</tr>
<tr>
<td>Inner lens</td>
<td>PMMA</td>
</tr>
<tr>
<td>Reflector</td>
<td>ABS</td>
</tr>
<tr>
<td>Circuit board</td>
<td>PP-GF, steel, copper, zinc</td>
</tr>
<tr>
<td>Rubber seal</td>
<td>EPDM glued</td>
</tr>
<tr>
<td>Fasteners</td>
<td>Steel screws</td>
</tr>
<tr>
<td>Inner cover</td>
<td>ABS+PC</td>
</tr>
<tr>
<td></td>
<td>PMMA</td>
</tr>
<tr>
<td></td>
<td>PMMA</td>
</tr>
<tr>
<td></td>
<td>PMMA</td>
</tr>
<tr>
<td></td>
<td>not required</td>
</tr>
<tr>
<td></td>
<td>EPDM clipped</td>
</tr>
<tr>
<td></td>
<td>Steel clips</td>
</tr>
<tr>
<td></td>
<td>PP-TV with circuit board</td>
</tr>
</tbody>
</table>

Fig. 6.5 Concept of typical recycling-optimized rear light cluster
to plug connections and coating operations. Electrical components cover the entire rear surface of the
light cluster. To improve recycling properties of a rear light cluster, while maintaining basic func-
tions, the decision was to make all parts of the assembly from PMMA (Automotore Engineering, 1996).

Optimizing the cluster in this way allows the entire composite light cluster to be recycled as a sin-
gle material. Additionally, all electrical components are integrated into a separate removable cover
that may be disassembled and re-used.

6.1.8 Recycled plastics in production

Several tons of polyurethane (PUR) foam derived from old headrests are used as the standard
source of materials for producing soundproofing. The supplier meets the demand for additional PUR
foam with waste left over from its own production.

Used polypropylene/ethylene propylene diene monomer (PP+EPDM) bumper covers and painted
production reject covers are used in production of new covers. After the bumper covers have been
ground, the recompounder melts the ground bulk and removes paint particles and other unwanted
solids by filtering. The part supplier then mixes recycled plastic with new plastic at a ratio of 30/70
recycled/new material.

Damaged bumpers returned by collision repair shops include SMC bumper supports also replaced
in the process. In the production of new bumper supports and sunroof frames, this found product
makes up 10% and 12%, respectively, of the basic materials used for making new components.

6.2 Experiences and Research on the Recovery and Recycling of Automotive Plas-
tics

6.2.1 Overview of scrap vehicle management

Every year, an estimated 11 million cars, buses, and trucks are scrapped in the U.S. and are man-
aged in the ways summarized in Fig. 6.6. At least 90 per cent of the scrapped vehicles are handled by
either one of the estimated 12,000 dismantlers and/or by one of the estimated 200 shredders located
throughout North America. The dismantling and shredding industry is well established in the recov-
ery of metal components that typically account for 70 to 75 per cent of vehicle mass.

The dismantling industry has focused traditionally on the recovery of part value from scrapped
vehicles rather than the recovery of material value. The types and numbers of vehicles processed vary
greatly among dismantlers. Dismantlers typically sell used parts at half of the price of new parts avail-
able from dealerships. Increasing competition and environmental pressures are compelling disman-
tlers to diversify and specialize. Consequently, more and more dismantlers are restructuring their op-
érations and adopting an “organized dismantling” approach to scrap vehicle management.

Engines, starters, generators, and other mechanical parts are typically reconditioned for resale.
Batteries (for lead and polypropylene), and catalytic converters (for platinum, rhodium and stainless
steel), are examples of components that are removed and sold to recyclers for further processing. A
large number of metal and plastic parts from taillight assemblies to fenders are removed and resold
into the used parts market. Plastic parts which are components of larger assemblies (such as doors,
front ends, seats, etc.) are typically sold as part of the complete assembly. Other plastics remain in the
stripped vehicles, which are stored in outside yards. Mechanics and the general public remove spe-
cific parts, as needed, from the vehicles while stored in the yards. In preparation for shredding, dis-
mantlers usually remove tires, exhaust systems including the catalytic converter, batteries, and fuel
tanks and recover fluids (anti-freeze, oils and air conditioner refrigerant).

The shredding industry reduces vehicle hulks to fist-sized pieces of material using massive ham-
mermills. The shredding process produces three streams of material: ferrous metals, shredder residue
Fig. 6.6 Expired vehicle flowsheet
- light fraction (also known as “shredder fluff”), and shredder residue - heavy fraction. The ferrous metals are sent to metal reclaimers for further recycling. The other two material streams, either singularly or collectively, are frequently referred to as automotive shredder residue (ASR). The non-ferrous and residual ferrous metals fractions in ASR are recovered by either the shredder operators, or by non-ferrous metal separators who purchase the ASR from the shredding industry. After the metals have been removed from the ASR, the remaining commingled residue is landfilled. However, the presence of fluids and heavy metal fines in the ASR pose disposal problems for the automobile shredding industry.

A variety of initiatives have recently been undertaken in Europe and North America to address this situation. In Germany, a tax on new cars has been proposed that would be used to pay for their eventual disposal. German automakers, in response to these initiatives, are now investing heavily in technology to recycle their products. In the Netherlands, the dismantling industry has formed an association known as STIBA, similar to the Automobile Dismantlers and Recyclers Association (ADRA) in the U.S., that helps develop standards and stimulates dialogue among its members. The Dutch government has started to implement an aggressive program to bring dismantling facilities into compliance with environmental regulations. In addition, several European countries are in the process of forming an international body governing the automobile recycling industry (Hoch and Maten, 1993; Jody et al, 1990).

In January 1992, the APC formed the Automotive Group to investigate the economically and environmentally sound disposal and recovery of post-consumer automotive plastics.

In February 1992, Ford Motor Co., Chrysler Corp., and General Motors Corp. jointly announced the formation of the Vehicle Recycling Partnership (VRP). The mandate of VRP is to increase the amount of recycled and recyclable materials in vehicles and to develop guidelines such as material selection and compatibility, and design for disassembly.

6.2.2 Plastic parts collection

With assistance from ADRA, five dismantlers participated in the research project. The dismantlers are located in Michigan, all within a 100-mile radius of one another. Wire baskets supplied by the hauler were used to store and transport the parts recovered. The collection phase of the project occurred between June and August 1992. Onsite storage of recovered plastics in wire baskets supplied by the hauler were used to store and transport the parts recovered. The collection phase of the project occurred between June and August 1992. Onsite storage of recovered plastics in wire baskets was an effective storage mechanism; but in spite of the signage placed on all baskets, the number of baskets led to confusion on the part of the dismantlers regarding what parts should be placed in which baskets. In order to maximize the quantities of material available for the reclamation trials, parts either already loose or easily accessible were collected from vehicles in the yards, which comprised approximately 75 per cent of the total material collected (Hock and Maten, 1993).

For the research program, the dismantlers were instructed to remove all contaminants from the parts recovered. It was recognized at the outset that this would be an arduous task and one that might prove detrimental to the recovery of large quantities of materials, however, dismantlers’ capabilities were the main focus of the research program recognizing that future initiatives depend on the level of source separation attainable.

The economics associated with the recovery of plastic parts/materials are directly related to: 1) the ease of disassembly; 2) the volume of material recovered per part; 3) the time to remove contaminants; and 4) the value of the material. Table 6.3 presents the data on the time recorded to remove the parts and remove the contaminants in preparation for recycling. Most parts were removed by brute force rather than methodical disassembly.
Table 6.3 Time study data

<table>
<thead>
<tr>
<th>Parts groupings</th>
<th>Average time to dismantle each part (seconds)</th>
<th>Average time to remove contaminants (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery tray</td>
<td>30.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Battery holddown clip</td>
<td>25.0</td>
<td>No physical contamination</td>
</tr>
<tr>
<td>Battery cover</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fender liner</td>
<td>105.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Fuel tank shield</td>
<td>100.0</td>
<td>No physical contamination</td>
</tr>
<tr>
<td>Engine splash shield</td>
<td>135.0</td>
<td>No physical contamination</td>
</tr>
<tr>
<td>Fan shroud</td>
<td>132.0</td>
<td>82.5</td>
</tr>
<tr>
<td>Garnish molding</td>
<td>14.2</td>
<td>7.5</td>
</tr>
<tr>
<td>Door trim panel</td>
<td>200.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Console</td>
<td>220.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Luggage compartment trim</td>
<td>23.3</td>
<td>10.0</td>
</tr>
<tr>
<td>Windshield washer container</td>
<td>28.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Radiator overflow reservoir</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiator and tank</td>
<td>105.0</td>
<td>17.5</td>
</tr>
<tr>
<td>Painted body panel (fender)</td>
<td>320.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Front &amp; rear facia</td>
<td>330.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Grille opening panel</td>
<td>280.0</td>
<td>Contaminants not removed</td>
</tr>
<tr>
<td>Bodyside molding</td>
<td>30.0</td>
<td>Contaminants not removed</td>
</tr>
<tr>
<td>Headrest</td>
<td>Too difficult to remove</td>
<td>Contaminants not removed</td>
</tr>
<tr>
<td>Armrest</td>
<td>30.0</td>
<td>Contaminants not removed</td>
</tr>
<tr>
<td>Wiring harness</td>
<td>47.5</td>
<td>Contaminants not removed</td>
</tr>
</tbody>
</table>

For the parts studied, Table 6.4 summarizes the percentage of parts typically sold for reuse. In some cases, these plastic parts were removed to dismantle other components for resale; the percentage of parts already dismantled is shown in Table 6.5. It can be seen that a large number of plastic parts are routinely removed by dismantlers and therefore available for recycling at minimal cost. Overall, eighteen different parts and six material types were successfully recovered. The polymers recovered were nylon, polypropylene, polyethylene, PVC, ABS, and SMC. Three parts and two material types were not collected. PPO & nylon alloy and polyester facia and fenders were not recovered because of their generally limited use to date, and their relatively high demand on the secondary parts market.

At present, dismantlers do not incur transportation costs, except for the disposal of the waste material that is taken directly to the landfill. The cost of transportation is typically included in the price that reclaimers pay for the scrap plastic. Therefore, a transportation contractor was brought in to facilitate the collection and distribution phases of the program. The transportation phase was designed to meet the following objectives:
- Integration with the participants’s existing recycling activity;
- Development of transportation logistics with long term viability; and
- Determination of transportation economics.

Although the contaminants were to have been removed by the dismantlers, many parts were still found to contain contaminants. In addition, many parts were found mixed in with other part/polymer groupings. Therefore, secondary sorting, decontaminating and bulking of the collected materials was done at the hauler depot. The material recovered was consolidated into gaylord boxes.
Table 6.4 Summary of survey data (% dismantled, % sold)

<table>
<thead>
<tr>
<th>Parts groupings</th>
<th>Parts currently dismantled AVG.%</th>
<th>Parts sold for reuse AVG.%</th>
<th>Part resale value AVG. $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery tray</td>
<td>0.0</td>
<td>5.0</td>
<td>9.16</td>
</tr>
<tr>
<td>Battery holddown clip</td>
<td>100.0</td>
<td>1.7</td>
<td>2.00</td>
</tr>
<tr>
<td>Battery cover</td>
<td>100.0</td>
<td>1.7</td>
<td>7.50</td>
</tr>
<tr>
<td>Fender liner</td>
<td>66.7</td>
<td>41.7</td>
<td>17.50</td>
</tr>
<tr>
<td>Fuel tank shield</td>
<td>100.0</td>
<td>20.3</td>
<td>11.67</td>
</tr>
<tr>
<td>Engine splash shield</td>
<td>6.7</td>
<td>20.0</td>
<td>6.67</td>
</tr>
<tr>
<td>Fan shroud</td>
<td>93.3</td>
<td>66.7</td>
<td>24.17</td>
</tr>
<tr>
<td>Garnish molding</td>
<td>43.3</td>
<td>2.0</td>
<td>6.00</td>
</tr>
<tr>
<td>Door trim panel</td>
<td>48.3</td>
<td>40.3</td>
<td>52.50</td>
</tr>
<tr>
<td>Console</td>
<td>46.7</td>
<td>5.0</td>
<td>39.17</td>
</tr>
<tr>
<td>Luggage compartment trim</td>
<td>36.7</td>
<td>2.3</td>
<td>6.00</td>
</tr>
<tr>
<td>Windshield washer container</td>
<td>40.0</td>
<td>31.7</td>
<td>7.17</td>
</tr>
<tr>
<td>Radiator and tank</td>
<td>33.3</td>
<td>30.0</td>
<td>Sold with Radiator</td>
</tr>
<tr>
<td>Painted body panel (fender)</td>
<td>100.0</td>
<td>96.7</td>
<td>125.00</td>
</tr>
<tr>
<td>Front &amp; rear facia</td>
<td>100.0</td>
<td>78.3</td>
<td>125.00</td>
</tr>
<tr>
<td>Grille opening panel</td>
<td>11.7</td>
<td>66.7</td>
<td>91.67</td>
</tr>
<tr>
<td>Bodyside molding (set)</td>
<td>0.0</td>
<td>5.0</td>
<td>26.67</td>
</tr>
<tr>
<td>Headrest</td>
<td>0.0</td>
<td>0.0</td>
<td>Sold with Seat</td>
</tr>
<tr>
<td>Armrest</td>
<td>26.7</td>
<td>3.7</td>
<td>11.67</td>
</tr>
<tr>
<td>Wiring harness</td>
<td>63.3</td>
<td>35.7</td>
<td>57.50</td>
</tr>
</tbody>
</table>

Notes: Refers to parts which are currently removed through “organized dismantling”. Includes parts recovered from “organized dismantling” and/or from vehicles in the yard. Resale value of parts is typically half of the price of new OEM parts available from dealers.

6.2.3 Parts recovery challenges

The research project identified several challenges associated with the recovery of automotive plastics and Table 6.5 presents some of the key project findings on a part-specific basis. Generally, the techno-economic viability of automotive plastics recovery is influenced by the following factors:

**Labeling of parts** - Many parts were not labeled at all, other parts were incorrectly labeled and labels were often difficult to find. As a consequence, dismantlers had difficulty in correctly identifying acceptable items for recovery and as a result 1) discarded parts that could otherwise have been reclaimed, 2) recovered parts not labeled because they appeared to be the same as other parts that were labeled, and 3) were unable to separate the mislabeled parts from the correctly labeled parts.

**Composition of parts** - The trend toward modular design requires that dismantlers spend considerable effort to remove the unwanted components from parts/materials desired. Contaminants were typically related to part design rather than the material composition. Examples are windshield washer bottles with internally mounted pumps, fan shrouds with integral fan motors, and interior door panels with carpeting, door handles, metal trim, etc.

**Segregation of parts into compatible polymer groupings** - Dismantlers routinely recover aluminum parts for material recycling purposes and the parts are segregated into material groups based on the part description (ie: radiator cores, wheels, miscellaneous dirty aluminum components, etc.). In contrast, the research project required the dismantlers to segregate the plastic parts not only by part description but also by polymer type. Dismantlers had difficulty in undertaking the latter segregation rigorously.
Simplification of the segregation requirements would likely result in maximizing plastics recovery.

**Ease of part dismantling** - The dismantling of some parts was hindered by the variety and number of fasteners used on different models and the lack of familiarity some dismantlers had in removing plastic parts.

**Removal of contaminants** - The dismantlers agreed to remove the contaminants, but some contaminants remained on the parts collected because the dismantlers overlooked them or did not view them as being contaminants. The many types of contamination tend to be related to the design of the components rather than the types of material used. Therefore, issues affecting sorting and decontaminating are presented below on a part-specific basis. Contamination affects the recyclability of parts by impacting on the economics of recovery and the reprocessing technology requirements. The following classifications are suggested to assist with contamination description:

- **Material contaminants**: Material contaminants include fillers (talc, wood, etc.), fiber reinforcements (glass, carbon, etc.), polymer structure (homopolymer vs. copolymer, melt flow, etc.), and additives (stabilizers, flame retardants, colorants, etc.). These contaminants are usually visually indiscernible and, therefore, become evident only during reprocessing.

- **Permanent contaminants**: Permanent contaminants include undercoating, hotmelt adhesives, sealants, paint, molded-in inserts, metallic substrates, etc. Removal of these contaminants at the dismantling stage is, in most cases, physically impossible.

- **Removable contaminants**: Removable contaminants include metal and plastic fasteners, plastic and paper labels, carpet, felt, gaskets, oils, grease, dirt, etc. The dismantlers removed most of the mechanical contaminants and the reclaimers attempted to remove the chemical contaminants.

- **Penetrating contaminants**: Penetrating contaminants include ethylene glycol, gasoline, brake fluid, etc. Some of the recovered parts (i.e: radiator end tanks, windshield washer and radiator overflow bottles, and brake fluid reservoirs) exhibited penetrating contamination and more reprocessing work must be done to determine the impact on recyclability.

For the recovery and recycling of automotive plastics to gain wider acceptance, it may become necessary to establish “Auto-Plastic Recovery Centers” (ARC) where post-consumer automotive plastics are sorted, separated and consolidated. Since the recovery of automotive plastics is complicated by the large number of parts and polymer types, ARCs could be set up to handle two distinctively different feedstocks; parts segregated into polymer groupings, and commingled parts/polymers. The ARC would be responsible for 1) sorting, consolidating and baling the parts, or 2) processing the plastic parts that may include shredding, granulating, washing, automated sorting and separating, drying, and packing the flake into gaylord boxes.

**Table 6.5 Plastics recovery findings**

<table>
<thead>
<tr>
<th>Parts</th>
<th>Project findings</th>
</tr>
</thead>
</table>
| Battery component          | - contamination includes metal brackets, battery acid and lead  
|                            | - metal is still the dominant material used to make battery trays and components |
| Fender liner               | - often removed to access suspension components for sale  
|                            | - contamination includes road tar, undercoating, and dirt  
|                            | - almost 50 per cent of parts were not recovered because of severe contamination |
| Fuel tank shield           | - primarily used on trucks to shield steel fuel tank  
|                            | - always removed in process of draining gasoline from tank  
|                            | - rarely labeled  
|                            | - contamination minimal and includes oil, grease and dirt |
| Engine splash shield       | - rarely sold on the secondary parts market  
|                            | - late models are fitted with facias that incorporate the design intent of the engine splash shield  
<p>|                            | - contamination minimal and includes road tar, oil and dirt |</p>
<table>
<thead>
<tr>
<th>Parts</th>
<th>Project findings</th>
</tr>
</thead>
</table>
| Fan shroud           | - approximately 70 per cent were not labeled  
                        - often removed to access radiator  
                        - often sold on secondary parts market  
                        - frequently damaged in accidents  
                        - late models have fan motor incorporated into design which is impossible to separate from plastic portion  
                        - contamination minimal and includes oil, grease, rubber grommets, and labels (plastic or paper) |
| Interior trim        | - approximately 60 per cent of parts are not labeled  
                        - except for unique & optional trim, rarely removed for resale  
                        - contamination includes metal brackets, rivets and trim, dissimilar polymer sub-components, labels (plastic and paper) glued to underside of part, sound insulation mats/felts glued to part, anti-rattle foam glued to part, and upholstery (carpeting and vinyl) bonded to part |
| Windshield washer container | - many late model parts have pumps mounted inside or outside the containers which can not be removed  
                                - sale for reuse ranges from 10 to 90 per cent  
                                - contamination includes ethylene glycol, electric pumps, metal brackets, molded-in electrical connectors and other plastics (black cover on Ford models)  
                                - approximately 50 per cent of containers were rejected because contaminants could not be removed |
| Radiator overflow reservoir | - very few sold on secondary parts market  
                                - do not contain mechanical and electrical components  
                                - contamination includes oil, grease and ethylene glycol |
| Radiator and tank    | - are fitted on approximately 80 per cent of radiators  
                                - nylon is only polymer used  
                                - must be removed prior to recycling radiator core  
                                - contamination includes gasketing, rubber vibration dampers, hoses and grommets, molded-in metal inserts |
| Painted body panel   | - plastics only started to be used in this application in the mid-80s; none were recovered  
                                - usually repaired if damage is minor  
                                - demand and resale value are high |
| Front & rear facia   | - removal of panel is very time consuming  
                                - contaminants include headlamp bezels, molded-in metal inserts, support brackets and plastic grilles  
                                - approximately 75 per cent of panels, either whole or in section, are sold on the secondary parts market  
                                - panels are repaired using standard fiberglass methods |
| Grille opening panel | - moldings are easily removed, however, reuse is often not possible because of damage to the decorative trim during removal  
                                - metal substrates and pressure sensitive adhesive tape are virtually impossible to remove |
| Bodyside molding     | - harnesses are now integrated into design of engine compartment and extend through the firewall, making removal for resale difficult  
                                - most wiring harnesses are left in the vehicle  
                                - the recovery of the copper and aluminium from industrial scrap wire & cable is already, being done |
| Wiring harness       | - composite structure complicates recyclability  
                                - now being incorporated in one-piece molded inner door panels |
6.2.4 Project objective

In recent decades, plastics have brought many benefits to automotive design and manufacture. Plastics have played a major role in enhancing fuel efficiency through light-weighting and improved aerodynamic design. Also, plastics are used in automobile construction for improved safety, durability, damage tolerance, and design freedom and offer opportunities for parts consolidation and reduced manufacturing costs. Plastics use increased from an average of 190 pounds per vehicle in 1980 to an average of 225 pounds per vehicle in 1990. Fig. 6.7 illustrates plastics applications in automobiles for the 1990 model year.

The increase in plastics usage in automobiles over the past decade will result in an increase in both the absolute amount and the proportion of plastics in ASR. In the absence of recycling options for automotive plastics and other materials comprising ASR, the value of automobile hulks will decline as the proportion of the hulk that must be disposed of by landfilling increases. This will have two consequences. Most immediately, landfills will see an everincreasing amount of non-recyclable material generated by the automobile recycling industry. Second, it will become progressively less attractive to recycle automobile hulks and the economic well-being of an important recycling industry will become increasingly uncertain.

Fig. 6.8 shows the percentage of vehicles, by model year, that are projected to be dismantled and ultimately scrapped in 1992. In 1992, only 13.6 per cent of the vehicles scrapped were be 1985 model year and newer and 53.6 per cent have been 1980 model year and newer. This demonstrates that “design-for recycling” initiatives implemented today will take on average 12 years to work their way through the system and impact on recyclability. In contrast, opportunities may already exist to expand dismantling activities to include plastics recovery, especially with “organized dismantlers” who are set-up to maximize the potential recovery of additional parts and materials.

As part of their overall activity to divert plastics from disposal, SPI commissioned a research project focused on reviewing the potential for the recovery of plastic components from automobiles. The

Fig. 6.7 Plastic application in 1990 model year automobiles (% by weight)
“Automotive Plastics Recovery and Recycling Research Project” was initiated in February 1991, under the direction of the American Plastics Council.

The Research Project focused on the recovery of automotive plastics prior to vehicle shredding. To this end, the project involved the dismantling, transportation, decontamination and segregation of specific plastic automotive parts followed by the reclamation of the polymers. The broad objective of the “Automotive Plastics Recovery and Recycling Research Project” was, therefore, to test capabilities for post-consumer automotive plastics recovery and recycling using the existing automobile dismantling, transportation and plastics recycling infrastructures.

6.2.5 Parts recovered

Table 6.6 lists the parts and polymers studied and the respective plastic content per part. The following criteria were used to select the plastic parts to be recovered in the research project:
- The parts should be easily dismantled;
- Their material composition should be virtually generic;
- The parts should have few or no sub-components;
- The parts should be common to the majority of original equipment manufacturers (OEMs); and
- The parts should contain significant volumes of material.

The criteria used in the selection of polymers suitable for recovery in the research project were as follows:
- The recycling capability and capacity is known to exist;
- The materials belong to a major resin type; and
- The generic use of material results in attractive volume potential.

![Fig. 6.8 Estimated percentages of model year automobiles scrapped in 1992](image-url)
Table 6.6 Parts studied in research program

<table>
<thead>
<tr>
<th>Parts groupings</th>
<th>Polymer</th>
<th>Average plastics content per part (Pounds)</th>
<th>(Kilograms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery tray</td>
<td>Polypropylene</td>
<td>1.0</td>
<td>0.45</td>
</tr>
<tr>
<td>Battery holddown clip</td>
<td></td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>Battery cover</td>
<td></td>
<td>0.3</td>
<td>0.14</td>
</tr>
<tr>
<td>Fender liner</td>
<td>Polypropylene</td>
<td>2.3</td>
<td>1.04</td>
</tr>
<tr>
<td>Fuel tank shield</td>
<td>Polypropylene</td>
<td>4.9</td>
<td>2.22</td>
</tr>
<tr>
<td>Engine splash shield</td>
<td>Polypropylene</td>
<td>2.0</td>
<td>0.91</td>
</tr>
<tr>
<td>Fan shroud</td>
<td>Polypropylene</td>
<td>3.8</td>
<td>1.72</td>
</tr>
<tr>
<td>Garnish molding</td>
<td>Polypropylene</td>
<td>0.3</td>
<td>0.14</td>
</tr>
<tr>
<td>Door trim panel</td>
<td>Polypropylene</td>
<td>3.0</td>
<td>1.36</td>
</tr>
<tr>
<td>Console</td>
<td>Polypropylene</td>
<td>3.6</td>
<td>1.63</td>
</tr>
<tr>
<td>Luggage compartment trim</td>
<td>Polypropylene</td>
<td>1.2</td>
<td>0.54</td>
</tr>
<tr>
<td>Radiator and tank</td>
<td>Polypropylene</td>
<td>0.8</td>
<td>0.36</td>
</tr>
<tr>
<td>Painted body panel (fender)</td>
<td>Polypropylene</td>
<td>7.0</td>
<td>3.18</td>
</tr>
<tr>
<td>Front &amp; rear facia</td>
<td>Polypropylene</td>
<td>10.0</td>
<td>4.54</td>
</tr>
<tr>
<td>Grille opening panel</td>
<td>Polypropylene</td>
<td>9.0</td>
<td>4.08</td>
</tr>
<tr>
<td>Bodyside molding</td>
<td>Polypropylene</td>
<td>3.5 (set)</td>
<td>1.59 (set)</td>
</tr>
<tr>
<td>Headrest</td>
<td>Polypropylene</td>
<td>0.2</td>
<td>0.09</td>
</tr>
<tr>
<td>Armrest</td>
<td>Polypropylene</td>
<td>0.3</td>
<td>0.14</td>
</tr>
<tr>
<td>Wiring harness</td>
<td>Polypropylene</td>
<td>10.0</td>
<td>4.54</td>
</tr>
</tbody>
</table>

6.2.6 Polymer reprocessing

The plastics recycling industry is in its infancy, with minimal sorting, washing, pelletizing, and compounding capabilities. Plastics recycling processes are highly sensitive to contamination; consequently, the need for intermediate processing to remove contaminants is viewed as absolutely necessary. To date, the recycling of post consumer plastics has largely been restricted to packaging materials. The recycling of engineering type resins, typically used in automotive applications, has been limited to clean post-industrial scrap and post-use battery cases.

In spite of the general lack of capable reclaimers, independent reclaimers were found for most of the post-use automotive plastics recovered including polypropylene, nylon, high density polyethylene, and PVC. Resin manufacturers offered to recycle ABS, polyester, and PPO & nylon alloy. The SMC Automotive Alliance committed to taking the SMC parts recovered. In some cases, reprocessing at full scale production facilities took place; in other cases, the quantities of material recovered restricted reprocessing to laboratory-scale equipment. Each reclamer utilized unique washing technologies using various combinations of hot and cold water, detergents, and surfactants. Each recycler was successful in obtaining commercial grade pellets from the recovered materials with exception of PVC which was not pelletized but successfully molded using the reclaimed flakes.

The reprocessed polymers were tested to determine the extent of degradation and the effects of contamination. This “real world” information will assist the resin manufacturers and the OEMs to assess the validity of their specifications and adjust the specifications where possible to permit the use of material with recycled content. Also, the test results help to evaluate the inherent value of the recycled polymer and the merits of upgrading the polymer’s material properties to yield a material of
The major challenges associated with the recycling of the parts studied are identified in Table 6.7.

The success of the reprocessing trials and the good results from the physical property testing indicate that the recycling of automotive plastic components is potentially technically feasible, and that the recycled polymers have sufficient inherent properties to be saleable. Specific application for the recycled material were not developed; consequently, the extent to which the recycled plastics could be reutilized, with or without compounding, in the manufacture of new automotive plastic components is unknown.

Table 6.7 Plastics recycling challenges

<table>
<thead>
<tr>
<th>Parts</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery components</td>
<td>• contamination with battery acid and lead</td>
</tr>
<tr>
<td>Fender liner</td>
<td>• the presence of as little as 1 per cent glass-filled material significantly reduced tensile/elongation values</td>
</tr>
<tr>
<td></td>
<td>• almost 50 per cent of parts were rejected because of severe contamination by road tar and undercoating</td>
</tr>
<tr>
<td></td>
<td>• separation of polyethylene from polypropylene required</td>
</tr>
<tr>
<td>Fuel tank shield</td>
<td>• large size and variations in size of parts could pose difficulty in achieving consistent size reduction, which in turn could limit the application of automated sorting equipment</td>
</tr>
<tr>
<td></td>
<td>• contamination minimal and includes oil, grease and dirt</td>
</tr>
<tr>
<td></td>
<td>• separating polyethylene from polypropylene required</td>
</tr>
<tr>
<td>Engine splash shield</td>
<td>• contamination minimal and includes road tar, oil and dirt</td>
</tr>
<tr>
<td>Fan shroud</td>
<td>• the presence of as little as 1 per cent glass-filled material significantly reduced tensile/elongation values</td>
</tr>
<tr>
<td></td>
<td>• separating polypropylene from nylon required</td>
</tr>
<tr>
<td>Interior trim</td>
<td>• contamination includes dirt, adhesives, labels, metal and mats/felt</td>
</tr>
<tr>
<td></td>
<td>• separating ABS and polypropylene from other plastics req’d</td>
</tr>
<tr>
<td>Windshield washer container</td>
<td>• ethylene glycol contamination is difficult to remove</td>
</tr>
<tr>
<td></td>
<td>• containers should be baled to adapt to handling and sorting systems currently used by post-consumer HDPE bottle recyclers</td>
</tr>
<tr>
<td></td>
<td>• separating polyethylene, polypropylene and nylon required</td>
</tr>
<tr>
<td>Radiator overflow reservoir</td>
<td>• containers should be baled to adapt to handling and sorting systems currently used by post-consumer HDPE bottle recyclers</td>
</tr>
<tr>
<td></td>
<td>• separating polyethylene, polypropylene and nylon required</td>
</tr>
<tr>
<td>Radiator and tank</td>
<td>• removal of metallic inserts is difficult</td>
</tr>
<tr>
<td></td>
<td>• ethylene glycol contamination is difficult to remove</td>
</tr>
<tr>
<td>Grille opening panel</td>
<td>• removal of metal and plastic contaminants should be done prior to grinding</td>
</tr>
<tr>
<td></td>
<td>• separating glass fibers from the SMC matrix required</td>
</tr>
<tr>
<td>Bodyside molding</td>
<td>• separating the Mylar® polyester film, pressure sensitive adhesive and metal substrate from the PVC is difficult</td>
</tr>
<tr>
<td>Wiring harness</td>
<td>• separating the copper and aluminium wire from the plastic insulation is required</td>
</tr>
<tr>
<td></td>
<td>• separating PVC from polyethylene</td>
</tr>
<tr>
<td>Arm rest</td>
<td>• separating the vinyl skin from the polyurethane foam is difficult</td>
</tr>
</tbody>
</table>

6.2.7 Preliminary economic analysis

Dismantling - The following four factors impact on the costs to the dismantler to collect automotive plastics:
- The degree of difficulty, and therefore the time required in removing the part;
- The extent of contamination of the part by non-plastic materials (e.g. metal clips) and/or incompatible resins;
- The plastics content per part; and
- The extent to which the plastic part may be removed from automobiles in the process of removing other parts for resale (where this is the case, the cost to collect the plastic part for recycling may approach zero since the part has already been removed).

The cost to dismantle the parts studied is estimated to range from $0.0 (effectively no cost) to $0.37 per pound, depending on the part. The cost for dismantlers to remove the contaminants is estimated to range from $0.0 to $0.11 per pound, depending on the part and the type of contamination. Combined with the cost to remove the contaminants, at the dismantling site, the total cost to recover the parts studied is estimated to range from $0.0 to $0.46 per pound.

**Transportation** - Transportation costs are influenced by the following factors:
- **Method of shipment:** The containers used for shipment (ie. gaylord boxes, baskets, bales, pallets, etc.) are somewhat dependent on the method and extent of volume reduction. It is likely that no one container option will fulfill the requirements for the recovery and collection of the various plastic parts that dismantlers could recover and, therefore, a combination of the different options may be needed.
- **Collection costs:** The collection costs are influenced by the location of the ARC with respect to the dismantlers. Presumably, the collection costs would be lower in urban areas than in rural areas. The cost analysis assumed that the dismantlers stockpile material until other dismantlers in the same vicinity have recovered enough material to fill a trailer and warrant the hauler to schedule a trip.
- **Distribution costs:** The distribution costs are influenced by the location of the ARC(s) with respect to the reclaimers. The cost analysis assumed that the method of transporting material is either in gaylord boxes or bale format, utilizing full trailers.

Hauling costs from the dismantler’s yard to an ARC have been estimated to range between $0.01 to $0.05 per pound, depending on the method of shipment and hauling distance. Haulage from an ARC located in central Michigan to the reclaimers who participated in the research project has been estimated to cost, on average, $0.02 per pound.

**Auto-Plastics Recovery Center (ARC)** - Depending on the level of processing undertaken at the ARC, the costs have been estimated to range from $0.02 to $0.10 per pound for parts collected in segregated material groupings, and to range from $0.14 to $0.35 per pound for parts/materials collected in commingled form.

**Reclamation** - The issues affecting the costs of reprocessing automotive plastics from the reclaimers perspective include:
- Type and quantity of contamination;
- Type and quantity of material grades used in same part;
- Quantity of feedstock available;
- Consistency of feedstock;
- Extent of reprocessing (flake vs. pellet); and
- Level of compounding required.

Depending on the level of processing done at the ARC, the reclamation phase could include debaling, manual removal of contaminants, shredding, granulating, washing, automated plastic sorting and separating, drying, extruding/compounding, and packing pellets into gaylord boxes. Reclamation costs have been estimated to range from $0.11 to $0.59 per pound, depending on the type of resin, type and degree of contamination, the level of compounding required, the volume of material processed and the level of processing required.

** Recovering and Recycling Automotive Plastics ** - Based on the economic analysis undertaken, the cumulative costs associated with recovery, by selective dismantling, through reclamation of the
automotive plastic parts studied fall within the range of $0.36 to $1.08 per pound, and average $0.72 per pound. These cost projections are a first-time attempt to understand the economics associated with the recovery and recycling of automotive plastics and, therefore, caution is advised when using the data outside the context of this study.

6.2.8 Final remarks

Dismantlers are generally not well equipped to recover plastics for recycling for the following reasons:
- They are generally unfamiliar with the different generic types of plastics;
- They are unaware of opportunities for plastics recycling;
- They are unaware of the basic quality control issues that must be addressed to implement plastics recycling (e.g. removal of contaminants, segregation of different types of plastic etc.);
- They are unaware of plastics reclaiming or recycling companies with whom they could work; and
- They are unaware of the material value of plastics.

Conversely, dismantlers already separate parts for resale from parts for recycling, and many understand the value of recovering materials. Dismantlers, therefore, are potentially well suited to help develop and implement systems for the separation and collection of plastic parts. In spite of the difficulties encountered by the dismantlers during this research project, there is enthusiasm among project participants to develop expertise in this area and to participate in continued recovery initiatives.

Difficulties in ensuring sufficiently high quality parts separation and contaminant removal at the dismantler highlight the importance of undertaking quality control procedures at the reclamer. Options for volume reduction processes at the dismantler’s yard will need to be compatible with the quality control procedures of reclaimers. Baling is preferable over shredding because it allows for part sorting, has lower capital cost, has higher compaction rates and is universally applicable to all materials.

The reclamation trials and test results conducted on the polymers studied demonstrate the potential for recycling post-consumer automotive plastics. Polymer variables such as type, manufacturer, compounder, parts producer, manufacturing process, and OEM specification present in automotive applications render the test results as general approximations only, but do provide a starting point from which to conduct more specific research. The pilot program included participation by both resin manufacturers and reclaimers, and the testing of the materials. The subsequent sharing of information has facilitated continued discussion and cooperation toward accelerating automotive plastic recycling.

The economic analysis undertaken showed that the cost to recover and recycle automotive plastics ranges from $0.36 to $1.08 per pound for the parts and polymers studied. The costs developed should be viewed as a starting point from which to conduct more detailed and part/polymer specific analyses with respect to economics and logistics of selective dismantling.

6.3 Polyurethanes recycling

6.3.1 Introduction

In automotive construction, polyurethanes are key materials in weight reduction and improvement of aerodynamic characteristics, both of which are crucial to the improvement in fuel economy of automobiles, and hence conservation of energy resources and reduction of harmful emissions.

Recycling of polyurethane materials results in further reduction of the energy requirements for materials such as RIM fascia. Inclusion of 10% recycled process scrap into the formulation results in a corresponding 10% reduction in the energy requirements for the part. Further energy savings can be realized by recovering the thermal energy //28-32 MJ/kg (12,000-14,000 BTU/lb)// embodied in the RIM parts at the end of their useful life. This reduces the total energy bill for polyurethane parts an additional 25-30% further solidifying the position of RIM polyurethanes as a material of choice in energy conserving, light weight, aerodynamic automotive parts.
The oil crisis of the mid 1970’s spawned a number of studies on the energy cost of using various materials in transportation applications. These studies produced a bank of information on the embodied energy contents of materials of automotive interest such as steel, aluminium, various thermoset and thermoplastic resins and the fillers associated with them in composites. Selected values are shown in Table 6.8. From these energy data, the energy consequences of producing a part from these materials could be calculated, if the dimensions of the part in the various materials were known (Farrisey, 1991).

The energy values in Table 6.8 were generated assuming that the metals contained a certain amount of recycled metal - 32% for steel and 30% for aluminium. However, for the plastic material, recycle was not a consideration. This part will describe the energy savings achievable through the recycling of polyurethane RIM materials, along with the energy savings attending the use of lightweight polyurethane automotive components during the life cycle of the vehicle.

Table 6.8 Energy contents of automotive materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Energy content Mj/Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Sheet (32% scrap metal)</td>
<td>62.2</td>
</tr>
<tr>
<td>Rim polyurethane</td>
<td>98.4</td>
</tr>
<tr>
<td>Glass fiber</td>
<td>51.3</td>
</tr>
<tr>
<td>Mineral filler</td>
<td>0.9</td>
</tr>
<tr>
<td>Gasoline</td>
<td>55.7</td>
</tr>
<tr>
<td>Aluminium (30% scrap metal)</td>
<td>241.3</td>
</tr>
</tbody>
</table>

6.3.2 Polyurethane energy life cycle

The chemical components of polyurethanes, as for most polymers, are derived from petroleum or natural gas feedstocks. Through the petroleum refining and reforming processes, are produced the isocyanates and polyols that are principal building blocks for polyurethanes. Through the skilled arts of the formulator and the requisite machinery, these chemicals are transformed into the legion of products - flexible and rigid foams, RIM and cast elastomers, adhesives, coatings, sealants and thermoplastics that make up the polyurethane industry (Fig. 6.9). It is the energy of these various steps, including the residual hydrocarbon fuel energy, that is incorporated into the value shown in Table 6.8. This latent fuel energy, which we have borrowed from the petroleum energy pool, its conservation and eventual thermal recovery will be discussed.

Also shown in Fig. 6.9 are recycle activities currently underway with process scrap from a variety of polyurethane applications. The most prominent of these is the very successful use of flexible foam scrap from slab and molded seat operations. This is rebonded into carpet underlay at a rate of 450 MM pounds per year. Other foam recycle applications include flexible foam for hydroponic gardening and rigid foam as an adsorbent of oil spills. Also, the use of regrind RIM scrap in RIM parts, a direct primary recycling effort, is well along in development. The hot pressing of RIM regrind offers another outlet for RIM scrap.

An additional method of recycling, available to polyurethanes especially, is chemical recycling, that is breakdown of the polymer with recovery of some or all of the building blocks - polyols and isocyanates.

Considerable research effort has been expended on the development of hydrolysis and glycolysis processes. Although useable polyols have been recovered from both processes, economic and quality uncertainties have inhibited extensive commercial exploitation of this alternative. However, development efforts continue, principally in Europe, at this time.

Material and chemical recovery are the priority recycle technologies from an environmental and
energy viewpoint. In this way, the bulk of the resources embodied in the product are recovered. However, at some stage recovery by these means becomes uneconomic or energy inefficient. At this point, recovery of the latent energy in the material may be prudent, thus returning to the energy pool some portion of the energy borrowed to fabricate the plastic originally. Also, as is will be shown, the energy consumed in the fabrication of these lightweight parts for automotive use, is far less than the energy saved over the corresponding steel parts during their life cycle.

6.3.3 Rim fascia

Automotive fascia continues to be a prominent application for RIM polyurethane materials, since its introduction in the 1970's. Research and development efforts on the recycle of process scrap has progressed significantly. The two technologies, inclusion of RIM regrind at the 10% level in RIM formulations and hot pressing of fusion bonding of regrind into automotive parts will be reported elsewhere. The consequences of these activities on the embodied energy of polyurethane parts is described below.

To construct the energy component of a RIM fascia, we need to assemble the energies of the various components, in the proper ratio. Using the data of Table 6.8, we calculate the overall energy for the 5.4 kg finished part, including a 10% scrap level, as 529 MJ (Table 6.9). Recycling of the scrap requires some energy, principally for grinding to the required particle size, which for this application is 177-297 microns. We can estimate that 4.0 MJ/kg are required for the grinding and blending of the material for reuse. Recasting the RIM formulation as 90% RIM urethane and 10% RIM regrind, we arrive at the figure in Table 6.9 of 81.9 MJ/kg for the embodied energy of this material. Since comparatively little energy is required to utilize the RIM scrap, its incorporation results in lowering the energy of the material by 10%. The fuel energy available in the regrind was not considered in the recycle application, since it has already been counted in the initial use of the material. If we now redo the energy cost for the RIM fascia with regrind, we obtain the expected 10% energy savings of 48 MJ.
per fascia. For a million parts, the energy savings are $48 \times 10^6$ MJ, or the equivalent of approximately 1.2 million liters of oil saved, simply by reuse of this scrap.

Of course, the more remarkable savings in RIM fascia accrue from the use of lightweight RIM materials. It is estimated that the weight save ratio for plastic materials is approximately 0.6; that is a one kilogram plastic part replaces a steel part weighing 1.67 kilograms. On this basis, the 73 million kilograms of RIM materials replaced about 122 million kilograms of steel, for a saving of 49 million kilograms of vehicle weight. Estimates of the fuel savings achievable through reduced vehicle weight vary from 5-9 liter per kilogram for a 162,000 kilometer vehicle lifetime. Using an average figure of 6.7 liter/kilogram, we calculate that the weight savings from these RIM parts result in fuel savings of 328 million liters of fuel over their lifetime, with attendant savings of 774 million kilograms in carbon dioxide emissions.

Table 6.9 Part energy content of Rim fascia with regrind

<table>
<thead>
<tr>
<th>Part weight</th>
<th>Rim</th>
<th>Rim plus 10% regrind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tot. wgt. (10% scrap)</td>
<td>5.4 Kg</td>
<td>5.4 Kg</td>
</tr>
<tr>
<td>Mater. energy</td>
<td>98.4 Mj/Kg</td>
<td>89.1 Mj/Kg</td>
</tr>
<tr>
<td>Part. energy</td>
<td>529 Mj</td>
<td>481 Mj</td>
</tr>
<tr>
<td>Ener. sav./Kg</td>
<td>-</td>
<td>8.9 Mj</td>
</tr>
<tr>
<td>Ener. sav./part</td>
<td>-</td>
<td>48 Mj</td>
</tr>
<tr>
<td>Ener. sav./1 mm parts</td>
<td>-</td>
<td>48*10^6 Mj</td>
</tr>
</tbody>
</table>

6.3.4 Automotive body panels

Automotive front fenders provide an interesting emerging application for consideration of the energy effects of recycling plant scrap. Table 6.10 presents the part dimensions and associated energies for fenders fabricated from RIM with 10% recycle and steel. As anticipated from the previous example, the use of 10% regrind saves about 10% of the energy usage for the part, in this case about 18 kBTU (19 MJ). And, as discussed earlier, even larger energy savings can accrue from the use of these lightweight materials.

From the weights in Table 6.10, and using the value for lifetime energy consumption of 6.7 liters per kilogram of incremental weight per 162,000 kilometers, we may assemble the life cycle energies for the RIM and steel parts. (Table 6.11) The lighter weight RIM part saves a total of 550 MJ over the corresponding steel fender (Fig. 6.10).

Table 6.10 Materials energy for automotive body panels

<table>
<thead>
<tr>
<th>Raw mat. ener., Mj/Kg</th>
<th>Recycle Rim</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part weight, Kg</td>
<td>3.00</td>
<td>4.60</td>
</tr>
<tr>
<td>Part thick., mm</td>
<td>3.56</td>
<td>0.89</td>
</tr>
<tr>
<td>Part dens., Kg/m³</td>
<td>1.27</td>
<td>7.74</td>
</tr>
<tr>
<td>Scrap, Kg</td>
<td>0.30</td>
<td>1.20</td>
</tr>
<tr>
<td>Total mater. used, Kg</td>
<td>3.30</td>
<td>5.80</td>
</tr>
<tr>
<td>Part energy, Mj</td>
<td>223.00</td>
<td>361.00</td>
</tr>
</tbody>
</table>
Table 6.11 Life cycle energy automotive body panels

<table>
<thead>
<tr>
<th></th>
<th>Rim with Recycle</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part energy, Mj</td>
<td>223</td>
<td>361</td>
</tr>
<tr>
<td>Use energy, Mj</td>
<td>784</td>
<td>1,196</td>
</tr>
<tr>
<td>Total energy, Mj</td>
<td>1,007</td>
<td>1,557</td>
</tr>
<tr>
<td>Energy saved, Mj</td>
<td>550</td>
<td></td>
</tr>
</tbody>
</table>

6.3.5 Energy recovery

When material and chemical recycle become no longer feasible, there remains the opportunity to recover energy values from scrap polyurethane materials. Typically polyurethanes contain 28–33 MJ-kg of thermal energy. In a well-designed and operated unit, a significant portion of this energy can be recovered with minimal ash and emissions within EPA guidelines. Actual efficiencies of 75–85% are achievable, yielding energy recoveries of 21–25 MJ-kg of scrap burned. In a development program with Voest-Alpine, clean conversion of mixed auto plastics scrap to fuel gas and inert slag was demonstrated via a high temperature gasification process. The fuel gas on combustion showed emissions well below the West German air quality standards.

The recycle/energy recovery process for RIM polyurethane materials reduces the net energy requirements for the material from 98.4 MJ/kg for the virgin material to 68.1 MJ/kg, a reduction of over 31%.

6.3.6 Conclusion

Thus, the life cycle is complete. By borrowing from the energy pool, we can fabricate materials which save more energy than they consume. For example, the 73 million kilograms of RIM materials used in 1989 had a total embodied energy content equivalent to 1.16 million barrels (183 million liters) of oil. On an equivalent basis, those same parts in steel would have required 1.22 million bar-
rels (194 million liters), a net savings for the RIM materials of 60,000 barrels of oil equivalents. If we add in the RIM recycle, the energy savings for RIM increases to 170,000 barrels (27 million liters) and to 420,000 barrels (67 million liters) if energy recovery is included (Fig. 6.11). And, in addition to this one-time energy savings in the part fabrication, we have an additional savings of 200,000 barrels (33 million liters) of oil energy saved each year in reduced fuel requirements for the lighter weight vehicle components. The net result is reduced consumption of non-renewable resources and lessened pressure on landfills.

6.4 Recycling Plastic Scrap in SRIM Composites

6.4.1 Introduction

While significant strides are being demonstrated in recycling virgin plastic materials, the task of separating mixed plastic streams, recycling painted parts or parts incorporating decorative coverings is often significantly more complex. Faced with the prospect of recycling scrap from cars, the automotive industry has to rationalize the economics of materials recovery and the cost burden of sorting stripped-down assemblies and separating incompatible plastics. While a large number of studies using mixed plastic streams have been conducted, the reclaimed products were shown to have limited utility resulting from poor mechanical properties (Babbington et al. 1993).

This section will discuss a novel recycle technique employing the SRIM (Structural Reaction Injection Molding) process, which has been shown to be very accommodating to incorporating a variety of recycled materials of mixed plastic streams of materials which have been painted or incorporate a dissimilar decorative covering.

The SRIM process was first commercialized in 1985 in a GM spare tire cover application. Since that time, applications have proliferated to include parts of a more structural nature, such as bumper beams. Extensive prototyping is currently ongoing for commercialization in future applications such as instrument panels, load floors and seat backs.

![Fig. 6.11 Energy consumption, Rim vs. steel](image-url)
6.4.2 SRIM Recycle core technology

The SRIM process consists of placing reinforcing material into a molding tool, closing the tool, impingement mixing a 2-component polyurethane resin system and injection of this mix into the tool cavity. The polyurethane system is cured, typically in 60 seconds, and the part is demolded (Babbington et al. 1993).

Evolving from recycle developments at the Dow Composites Laboratory in Taegerwilen, Switzerland, the SRIM process was modified to accommodate coarse recycle granulate material. The SRIM recycle process consists of sandwiching coarse plastic regrind material between layers of fiberglass reinforcement. The fiberglass and regrind sandwich structure is loaded into a molding tool and the two-component polyurethane resin system is then injected into the cavity as is done for the conventional SRIM process, encapsulating the reinforcement and regrind within the matrix (Fig. 6.12).

Depending on the complexity of the part being fabricated, the reinforcing material may go through a preforming process to allow the reinforcement to readily conform to the contours of the molding tool. Typically for automotive applications, the reinforcing materials is some type of fiberglass material which meets the cost and performance requirements of the application.

There are two types of preforming techniques employed in shaping the fiberglass reinforcement. The first consists of heating a binder-coated reinforcing material to the softening point of the binder and then placing this in a preforming tool to shape and cool the reinforcement. Significant strides have been made over the past few years in automating and optimizing this process.

The second preforming technique involves chopping the reinforcement material, along with a binder material, onto a perforated screen. Suction from air flow being pulled through the screen holds the reinforcement is positioned on the screen, the binder is set and the part is removed from the screen.

Both preforming processes have been demonstrated to accommodate the regrind material. In the stamped preforming process, the regrind materials is dispersed on the lower half of the reinforcing mat once the reinforcement is cut to size. The top layers of reinforcement are then positioned over the regrind and the reinforcement is then either placed directly in the molding tool if no forming is required, or passed through an infrared oven for softening the binder prior to stamping the preform.

In the directed fiber process, half of the reinforcing materials is sprayed on the perforated screen. The recycle granules are then spread over the reinforcement on the screen. Once in place, the remaining directed fiber reinforcement is sprayed into place and set with the binder. Secure positioning of the regrind to the preform is dependent on the amount of fiberglass sprayed on the screen in conjunction with the air flow being pulled through the screen. As would be expected, horizontal directed fiber preform screens minimize problems in dispersion and subsequent movement of the recycled granulate.

For lab prototype evaluations of this recycle technique, the granulate material can be dispersed manually onto the fiberglass reinforcement using a simple shaker dispenser. In a production setting, automatic dispenser would be used to shuttle across the reinforcement to rapidly and consistently distribute the recycle granules.

Fig. 6.12 Schematic of SRIM recycle core technology
Extensive work has been done to examine the parameters influencing processability and mechanical properties employed with this recycle technique. The effects of recycle level and granulate particle size on processability and physical properties were previously examined and reported. It was found that incorporation of the recycle material between the reinforcing material actually increased the flexural moduls of the part as seen in Fig. 6.13. With the recycled granulate at the center of the laminate, the fiberglass reinforcement is constrained at the surfaces of the part, increasing the flexural modulus of the composite. Up to 30% granulate (by weight of the total part) can be accomodat-ed with this recycle technique.

6.4.3 Versatility in recycle core material type

To evaluate the versatility of the SRIM recycle core process with respect to material type, a variety of automotive plastic components were collected for evaluation in this study. These parts consisted of both thermoplastic and thermoset materials either with or without paint or decorative covering as listed below.
- Fascia: painted polyurethane RRIM (Reaction Injection Molded)
- Interior door panel: Low density RRIM (LDRRIM) with decorative vinyl covering
- Door panel: painted polycarbonate (PC)/ABS
- Instrument panel: PC/ABS with foam and vinyl decorative covering
- Instrument panel: PC/ABS with foam and decorative covering removed
- Arm rest: ABS with foam and vinyl skin covering
- Bumper beam: polyurethane SRIM

6.4.4 Experimental procedure

These seven application sources for the recycle evaluation were reduced through a granulator. Type of granulator, screen size and condition of the equipment (blade sharpness) all can influence the size and shape of the particle obtained. Due to the high glass content of the SRIM bumper beam (approximately 50% by weight), the material tended to shred into approximately 1/2 inch lengths of resin coated glass fibers during the granulation step. This was not the case for the polyurethane RIM fascia parts or the thermoplastic materials which resulted in more distinct granules.

Regrind material was screened to determine the distribution of particle size obtained from the granulator for each material. The regrind material required for the SRIM recycle sandwich core process must be sufficiently large to prevent filtration of the recycle granulate through the reinforcement during preforming or handling operations, but small enough to meet the space restriction be-

![Fig. 6.13 Effect of recycle level on modulus](image-url)
tween the reinforcement for the given plaque thickness. While the granulators used to size the materials varied, all materials had been passed through a 3.2 mm screen to obtain the majority of regrind particles < 2.8 mm. Similar particle size distributions were obtained for the various plastic parts.

To compare the effect of regrind substrate on processability and physical properties, 3 mm thick, 63.5 cm x 63.5 cm plaques were molded utilizing the SRIM recycle core process. Thirty percent continuous strand mat reinforcement (by weight) was incorporated into the molded plaque. A control panel containing no regrind material was also prepared at this same reinforcement level.

A level of approximately 20% by weight recycle content was incorporated into the SRIM part for the RRIM fascia regrind. The bulk densities of the other recycle components varied, due to the presence of the foam and decorative covering on several of the parts. Approximate equivalent bulk volumes of the regrind particles were therefore compared, to determine sensitivity of recycle material type on processability and physical properties. The effect of incorporating material “fines” (particles < 1.18 mm) in with the regrind granules, was evaluated for both the RRIM fascia and PC/ABS door panel regrind particles.

Process conditions used in molding the SRIM plaques containing the regrind material are summarized in Table 6.12.

### Table 6.12 Process parameters for SRIM with recycle core

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SRIM with recycle core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin type</td>
<td>Spectrim® mm 310 polyurethane resin</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>Continuous strand mat 4 plies, 1oz/sq. ft. Certainteed U809 30% by weight</td>
</tr>
<tr>
<td>Regrind</td>
<td>Varied 0-20% by weight (of the total part) 0-27.2% by volume</td>
</tr>
<tr>
<td>Mold Temperature</td>
<td>63 degrees C</td>
</tr>
<tr>
<td>Component Temperature</td>
<td>Isocyanate 37.8 degrees C Polyl 46 degrees C</td>
</tr>
<tr>
<td>Injection rate</td>
<td>185 g/sec</td>
</tr>
<tr>
<td>Shot Time</td>
<td>5.2 seconds</td>
</tr>
<tr>
<td>Cure Time</td>
<td>90 seconds</td>
</tr>
</tbody>
</table>

*Trademark of the Dow Chemical Company

6.4.5 Processing results

Excellent liquid resin fill of the SRIM panels was seen for all of the recycle materials with the exception of the part containing the arm rest regrind. This regrind material had an extremely low bulk density and although only 10% (by weight) of the regrind material was incorporated into the SRIM part, exceptionally high backpressure and incomplete fill of the SRIM plaque corners was noted. Cause of the non-fill is the result of the large surface area of the foamed substrate impeding flow and compressing under the SRIM material flow front.

Table 6.13 summarizes the recycle level employed and the backpressure noted for each of the recycle materials. None of the recycle materials showed any tendency to wash away from the inlet port during resin injection. The effects of particle “fines” on processability of the recycle containing part is also summarized in Table 6.13. Elimination of the fines in the recycle stream reduced the backpressure seen in injecting the polyurethane components into the cavity.
Table 6.13 Process conditions noted with various regrind materials

<table>
<thead>
<tr>
<th>Part description</th>
<th>Regrind level (wt. %)</th>
<th>“Fines”</th>
<th>Backpressure (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fascia-painted PU RRIM</td>
<td>20</td>
<td>with</td>
<td>20.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>without</td>
<td>0</td>
</tr>
<tr>
<td>Intr. door panel-LDRRIM</td>
<td>15</td>
<td>with</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>without</td>
<td>6.9</td>
</tr>
<tr>
<td>Door skin-Painted PC/ABS</td>
<td>20</td>
<td>with</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>without</td>
<td>0</td>
</tr>
<tr>
<td>I/P - PC/ABS with foam/pvc</td>
<td>15</td>
<td>with</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>without</td>
<td>14.0</td>
</tr>
<tr>
<td>I/P - PC/ABS</td>
<td>20</td>
<td>with</td>
<td>20.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>without</td>
<td>0</td>
</tr>
<tr>
<td>Arm rest - ABS w/foam/pvc</td>
<td>10</td>
<td>with</td>
<td>34.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>without</td>
<td>6.9</td>
</tr>
<tr>
<td>Bumper Beam - PU SRIM</td>
<td>20</td>
<td>with</td>
<td>27.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>without</td>
<td>13.8</td>
</tr>
</tbody>
</table>

6.4.6 Mechanical property results

To determine the sensitivity of the SRIM recycle core process to the recycle material type comprising the core layer, tensile, flexural, and izod properties were evaluated. In addition, part specific gravity was measured on each of the recycle containing plaques to determine if the SRIM part weight could be reduced through incorporation of the various core materials. Plaques containing the recycle material were compared to a control plaque which did not contain the regrind. The glass content was the same in both the control and the recycle plaque (i.e. four layers of continuous strand mat).

Recycle Material Type on Mechanical Properties: the various types of recycle materials evaluated in the SRIM core, an improvement in the flexural modulus was noted over the control plaque, which did not contain the recycle material. An increase in tensile modulus over the control plaque was also noted for the PC/ABS door panel, instrument panel, and the SRIM bumper beam recycle-containing plaques. This would be expected due to the higher tensile modulus of these recycle materials compared to the unreinforced matrix polyurethane resin it is displacing. Both notched and unnotched izod properties were comparable between the various recycle materials as well as compared to the control.

Recycle Material Type on Part Specific Gravity: The specific gravity of the molded SRIM plaque containing the various regrind materials was measured and compared to the control plaque which did not contain the regrind. The majority of the recycle containing plaques had specific gravities comparable to the control, despite the low bulk densities of several of the regrind materials containing a foamed-in-place decorative covering. Due to the low compressive strength of the foamed regrind materials, this recycled material compressed during fill of the SRIM part, negating any advantage toward reducing the SRIM part weight. Only the low density polyurethane RRIM interior door panel resulted in a lower specific gravity than the control plaque. Incorporation of the polyurethane SRIM bumper beam recycle material into the SRIM sandwich core part increased the specific gravity of the resulting part due to the increased specific gravity of this recyclate.

Recycle Material “Fines” versus Mechanical Properties: While the presence of material particle “fines” had been shown to influence the processability of the SRIM plaque, mechanical properties of the resulting plaques were not effected.
Consistency of Properties of Plaques Containing Regrind: To illustrate the consistency of the properties across the plaque obtained with the recycle material, given in Table 6.14, are the percent coefficients of variance obtained for the various recycle material plaques compared to the control for the flexural and tensile analysis. Coefficients of variance were for the most part comparable to those obtained for the control.

Table 6.14 Consistency of properties of plaques containing regrind

<table>
<thead>
<tr>
<th>Regrind Material</th>
<th>Percent Coefficient of Variance</th>
<th>Specific Gravity</th>
<th>Tensile Strength</th>
<th>Tensile Modulus</th>
<th>Flexural Strength</th>
<th>Flexural Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.3</td>
<td>6.0</td>
<td>5.0</td>
<td>6.5</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>Fascia-painted PU RRIM</td>
<td>0.8</td>
<td>5.0</td>
<td>7.8</td>
<td>9.7</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Intr. door panel - PU LDRRIM</td>
<td>0.6</td>
<td>5.0</td>
<td>8.8</td>
<td>6.8</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>Door skin-Painted PC/ABS</td>
<td>1.8</td>
<td>8.0</td>
<td>9.0</td>
<td>7.7</td>
<td>12.6</td>
<td></td>
</tr>
<tr>
<td>I/P-PC/ABS with foam/pvc</td>
<td>1.2</td>
<td>6.0</td>
<td>6.7</td>
<td>6.7</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>I/P - PC/ABS</td>
<td>0.5</td>
<td>12</td>
<td>11</td>
<td>7.5</td>
<td>13.2</td>
<td></td>
</tr>
<tr>
<td>Arm rest - ABS w/foam/pvc</td>
<td>1.4</td>
<td>13</td>
<td>19</td>
<td>14.6</td>
<td>10.1</td>
<td></td>
</tr>
<tr>
<td>Bumper Beam - PU SRIM</td>
<td>1.1</td>
<td>14</td>
<td>8.8</td>
<td>7.9</td>
<td>10.1</td>
<td></td>
</tr>
</tbody>
</table>

6.4.7 Economic estimates

Since the recycled granulate material is replacing virgin polyurethane resin in the composite part, one would anticipate seeing a reduction in the cost of the final part employing the SRIM regrind sandwich core technology. To quantify this cost reduction, one needs to look first at the cost of obtaining and then granulating the recycle material. A collection system for most reclaimed automotive plastic parts, especially thermoset and engineering thermoplastic materials, is not yet in place, so it is difficult to assign a cost to reclaimed material. An assumption made for this exercise is that the recycled material used is from in-plant molder part scrap with no cost assigned to the scrap other than that incurred in sizing the regrate material.

Since the regrate technique discussed in this section only requires the parts to be ground to a coarse granulate, sizing costs are kept to a minimum. An estimate of size reduction costs for the coarse recycled granulate is shown in Table 6.15. Factoring in capital, labor and maintenance costs for a 363 kg/hour regrate rate, approximate size reduction cost was $0.16/kg to achieve a < 2.8 mm granule.

With this estimate in mind for regrate costs, one could approximate the raw material cost savings when the regrate is incorporated into the composite part. Table 6.16 illustrates some typical raw material cost savings for a variety of regrate contents. Given that raw material costs typically average 50-75% of the final part cost, these savings are significant to the overall part cost.

6.4.8 Applications

The SRIM regrate core technique is unique in that a variety of regrate material types can be accommodated and an IMPROVEMENT in flexural modulus of the part is seen with the incorporation of the regrate core layer. As pressure mounts for automotive components to contain regrate content, the SRIM regrate core process gives the automotive supplier an outlet for recycling troublesome plastic parts which are comprised of mixed plastic streams, have been painted or contain a decorative covering. Automotive applications such as instrument panel topper pads, rear parcel shelves, load floors...
and close out panels appear as likely candidates for incorporating recycle content via the SRIM corke process.

Table 6.16 Effect of recycle material on part material cost

<table>
<thead>
<tr>
<th>Recycle Content (%)</th>
<th>Resin Content (%)</th>
<th>Glass Content (%)</th>
<th>Raw material cost/kg</th>
<th>% Saving w/recycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>70</td>
<td>30</td>
<td>2.63</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>30</td>
<td>2.40</td>
<td>8.7</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>30</td>
<td>2.14</td>
<td>17.3</td>
</tr>
<tr>
<td>30</td>
<td>40</td>
<td>30</td>
<td>1.95</td>
<td>26</td>
</tr>
</tbody>
</table>

Assume recycle cost is $0.16/kg ($0.073/#)
Assume resin cost is $2.43/kg ($1.10/#)
Assume glass cost is $3.09/kg ($1.40/#)

6.4.9 Conclusion

An economically viable recycle technique has been identified employing the SRIM process with coarse recycled plastic materials sandwiched between the fiberglass reinforcement in the part. Due to the fiberglass reinforcement being constrained at the surface of the part with the recycled material forming the inner core, an increase in the flexural modulus of the molded part is seen.

A variety of recycled materials from typical automotive applications including painted fascia and door panels, vinyl clad instrument panels, armrests and inner door panels and SRIM bumper beams have been shown effective in increasing the modulus of the SRIM part when incorporated as the re-
cycle core layer compared to the control panel not containing recycle material. This technique offers the automotive parts supplier an outlet to recycle incompatible mixed plastic streams, painted or decoratively covered plastic parts, while recognizing an increase in the stiffness of the resulting SRIM part. Applications such as instrument panel topper pads, rear parcel shelves, load floors and close out panels which would benefit from such increased stiffness, are likely targets for incorporating this recycle technology.

Since the recycled granulate material is replacing virgin polyurethane resin, a reduction in the final part cost employing the inner recycle core material is anticipated.

6.5 The Recyclability of PVC Covered Low Density RRIM Interior Automotive Trim Components

6.5.1 Introduction

Lightweight reinforced RIM polyurethane substrates are increasingly being specified for fully covered automotive applications such as interior door panels, instrument panels, and package shelves. In addition to offering a 30-40% weight reduction over conventionally used substrate materials, consolidation in manufacturing steps are achieved by molding direct to polyvinylchloride (PVC), polyurethane (PU) and/or textile coverings. Weight reduction and consolidation of manufacturing steps lead to considerable part cost savings. Styling trends toward complex, deep drawn door panels, integrated with instrument panel modules, are easily fulfilled with low pressure RIM.

The LD-RRIM process uses two-stream lance cylinders for resin injection. It thus allows molders to take advantage of established RIM recycling technology by incorporating pulverized PVC covered LD-RRIM mold scrap into the original part. Covered polyurethane door panels, stripped of metal fixtures, can be granulated and pulverized using standard grinding equipment. The powdered plastic “re-grind” can be added as an inexpensive extender, at the time of filler addition, to further reduce material costs. Of all one-step, covered door panel processes, the LD-RRIM approach is the only process that has demonstrated the incorporation of covered substrate scrap as regrind, without first separating the substrate from coverstock. The “regrind process” is a safe, simple, and economical method for recycling vinyl covered LD-RRIM polyurethane components (Weaver, 1993).

Strapazzini Auto S.R.L. (Pesaro, Italy) pioneered the production of fully covered RRIM door panels for European OEMs. This process typically uses in-mold decorating techniques which employ dissimilar covering materials (i.e. PVC and fabric) over the reinforced polyurethane substrate.

Corporate Average Fuel Economy (CAFE) requirements in the U.S. have provided a competitive opening for lighter weight materials, first achieved with LD-SRIM technology, and now more economically met with LD-RRIM.

The first commercial use of LD-RRIM in the U.S. has been the 1994 G.M. Corvette door panel molded by United Technologies Automotive, Inc., under a license from Strapazzini. These door panels molded with LD-RRIM system from The Dow Chemical Company meet General Motors 2740M door panel performance criteria.

The interest in LD-RRIM as a door substrate material is gaining the attention of global OEMs. This interest is induced not only by its cost effective weight reduction attribute, but also by the relative simplicity of the LD-RRIM process (Weaver, 1993).

6.5.2 LD-RRIM vs. LD-SRIM process

In the LD-SRIM process, a pre-cut fiberglass mat is placed in the tool cavity prior to open-pour robotic dispensing of the polyurethane components. Open mold dispensing is utilized to avoid high density regions in the substrates (closed mold injection produces densification directly under the injection point). The LD-SRIM process requires dedicated labor and capital (typically +$400K for ven-
tilation, dies, press, and shuttle beds) to cut and handle the fiberglass mat. Up to 20% of the virgin mat becomes expensive trim scrap which is typically landfilled.

The LD-RRIM process incorporates the filler in the liquid resin, avoiding reinforcement trim scrap and minimizing labor and capital requirements. The filler, typically packaged in totes, is blended at the molder manufacturing site using a low-shear mixing system (typically $150K).

In the LD-RRIM process, coverstock is positioned in the tool cavity using a vacuum assist. Fasteners and energy management systems are positioned in the core, and the tool is closed for resin injection.

Conventional two-stream lance cylinder equipment with hardened steel mixheads is used to dispense the liquid components into the closed mold, avoiding the need for robots.

Once injected, the liquid flows through the mold cavity and mechanically secures fasteners and energy managing devices during polymerization. In LD-RRIM, the substrate density and filler distribution is uniform throughout the part. This allows the incorporation of molded-in ribs for stiffness; an added benefit of the LD-RRIM process not easily attainable with LD-SRIM.

As is the case for thermoplastic injection molding, rib and boss read-through can occur. In the case of low density RIM, this read-through results primarily from the exotherm of the polyurethane reaction. To avoid distortion at demold (a function of demold time and part thickness), the temperature of the polyurethane polymer must be reduced to below its glass transition temperature. Otherwise, visible post-mold expansion of the polyurethane (the inverse of thermoplastic sink marks) will occur under thick cross-sections.

The density of RRIM substrates varies with the amount of carbon dioxide generated from the reaction of polyisocyanate and water (a component in the liquid resin), and with the volume of material injected into the tool cavity (packing). The in-mold pressure varies with LD-RRIM substrate density. Overpacking the tool increases the in-mold pressure. In-mold pressure is used to size RIM clamps, based on the surface area of the part. Fifty ton clamps are typically used for low density RIM door panel production; this provides a 50% safety factor in the tonnage needed to counteract the in-mold pressures generated during the molding process.

Low cost aluminum production tooling is used in both LD-SRIM and LD-RRIM because of the inherently low in-mold pressure of these liquid molding processes (< 50 psi). In contrast, thermoplastic injection molding of door panels generates pressures in excess of 1000 psi, and thus requires the use of more expensive steel molds. Low cost tooling is an inherent attribute of low density RIM over thermoplastic injection molding.

Lightweight aluminum tools are easily cycled on a carousel around one RIM injection unit. Two operators typically run a four mold carousel, with one fully covered LD-RRIM panel being produced every 60 seconds. Independent RIM clamps can also be utilized for production of fully covered door panels. Figures 4 and 5 depict these two possible molding scenarios.

Mechanical properties of lightweight RIM composite parts, whether LD-SRIM or LD-RRIM, depend primarily on the reinforcement level and composite density. The mechanical properties of a LD-RRIM system containing 15 weight percent milled fiberglass reinforcement and having a specific gravity of 0.62 passes on OEM door panel performance specification.

Previous studies (Wearier, 1992; Laux et al., 1991) showed that LD-SRIM and LD-RRIM substrates have essentially equivalent mechanical properties at a reinforcement level of 15 weight percent hammer-milled glass, wallastonite or fiberglass mat; densities within the range of 0.5-0.7 g/cc; and thicknesses of 3.0-4.0 mm. These characteristics are typically specified for lightweight door substrates.

6.5.3 Recyclability
RIM regrind process development began in 1987 with the primary focus of reducing part costs by recycling painted and unpainted fascia scrap, generated in the production process, into virgin.poly-
mer. RIM fascia molders typically generate between about 5 and 10% scrap consisting of the sprue and runner from each part, molding rejects, and paint defects. This simple process, developed by the Dow Chemical Company, has been successfully demonstrated as a method to recover in-plant scrap generated in the production of PVC covered in-plant scrap generated in the production of PVC covered LD-RRIM door panels.

Covered LD-RRIM door panels, stripped of metal add-ons, are typically composed of approximately 50% by weight PVC covering and 50% substrate. The polyurethane substrate is composed of 85% by weight polyurethane and 15% reinforcing filler.

Vinyl covered door panels, with an approximately 150 mm PVC overhang door panels, with an approximately 150 mm PVC overhang along the edges, were singly fed into a 30 HP Hi-Torque Shredder and reduced to 76 mm wide strips. The parts with the PVC overhang are representative of irreparable scrap panels produced from a molding operation (not trimmed out). The strips were then fed into a particlizer (Hi Torque Particle-izer, 75 HP) at approximately 254 kg/hr and further reduced to 6.4 mm chips. These chips were then fed at approximately 227 kg/hr into a Schultz-O’Neill pulverizer (20 HP), and reduced to a 180 micron (-80 mesh) powder.

6.6 Recycling low-density SRIM interior trim panels

6.6.1 New LD-SRIM techniques

Low-density structural reaction injection molding (LD-SRIM) has grown in popularity with automotive design engineers during the last 20 years because of its design flexibility and weight saving potential. When molded in its traditional composite density range of 0.5-0.6 g/cm³, LD-SRIM offers greater than 40% weight saving compared with an equivalent acrylonitrile-butadiene-styrene (ABS) door panel. Recent advancements in LD-SRIM technology have led to even lower part material densities, which can be as little as 0.3 g/cm³ with new generation LD-SRIM. Design flexibility is enhanced by varying the glass content and part thickness, allowing the specific physical properties for the application to be met without adding unnecessary mass. Processing simplicity and low cost of the LD-SRIM process add to the benefits.

Now, two processes are available for making LD-SRIM door panels. In one, the door panel substrate is molded and then decorated. The decorating step uses a foam-in-place (FIP) process to inject a flexible foam between a formed polyvinyl chloride (PVC) skin and the substrate. The FIP flexible layer gives the PVC surface a “soft feel”. In the second process, the composite substrate is molded directly onto a “soft-feel”, expanded PVC skin producing a decorative part in one step. This pour-behind vinyl process reduces later processing and cost.

In addition to the density reduction of SRIM, productivity has been increased by incorporating internal mold release (IMR) agents into the LD-SRIM chemistry. These IMR agents act as lubricants that come to the surface of the part during molding, allowing it to release from the metal tool surfaces. IMRs improve costs and productivity by reducing the need to apply an external mold release (EMR). Reduced cycle times, lower perunit labor costs, and less downtime for mold cleaning contribute to their benefits. Current polyurethane IMRs produce up to 100 releases between applications of EMR in production environments. Water-based EMR can be used with this technology, allowing reduction of volatile organic compound (VOC) emissions.

The popularity of LD-SRIM for door panels has led to its use in other interior trim applications including package trays, quarter panels, sunshades, and seat pans. With more applications, attention to the environmental performance of LD-SRIM has increased. Until now, recyclability of LD-SRIM has been difficult due to the glass fiber composite nature of the material.

A new physical recycling scheme for in-house process scrap at ICI Polyurethanes uses size-reduced LD-SRIM as a filler for the production of new panels with recycled content. This recycling
process consists of two segments: size-reducing the LD-SRIM, and incorporating the size-reduced LD-SRIM into new parts.

6.6.2 Recyclate method
Scrap from production of LD-SRIM interior panels consists of glass fibers with composite material made up of rigid polyurethane foam and glass reinforcements that are trimmed from the panel after the molding process. These trimmings, termed outfall, with scrapped panels, constitute a bulky solid waste stream that would normally be sent to landfill. About 1000 kg of material was collected from the waste stream of an LD-SRIM molder during normal operations. The bulky trimmings were reduced to nominal 10-25 mm chips using a three-knife, open rotor granulator with a 25 mm screen. This step was only a convenience to achieve a feedstock size that could physically be introduced to the pulverization equipment.

A hammer mill and a pellet mill were used to test pulverization efficiencies. These widely recognized technologies were checked for processing rate and size reduction efficiency in achieving the desired LD-SRIM particle size.

Discharge from the lab-scale pellet mill was fed into a 450 mm mechanical sieve shaker equipped with 300- and 112-µm sieves. This generated three size-reduced fractions, > 300 µm (overs), < 300 and > 112 µm (middle cut), and < 112 µm (pan).

Feedstock for the lab-scale hammer mill was moved into the impact zone with a screw augur. Hammer links attached to a rapidly rotating axle impacted the feedstock on a plate. A thin screen with holes of 0.7 mm diameter retained the feedstock within the work zone until it was fine enough to fall through. An air-assisted system collected and cooled the resulting powder. The collected powder was later sieved using the same 450 mm mechanical sieve equipped with the 300- and 112-µm screens used with the pellet mill.

The hammer mill was most efficient in reducing the LD-SRIM scrap granulate to a fine powder of less than 212 µm, with yields of 80% or higher. The pellet mill was efficient with only 60% of the first pass output in the desired size range. Although the one-pass efficiency of the hammer mill was high, considerable wear was observed in the mill. The screens were quickly abraded by the powder, as expected. However, the high abrasion of the tungsten carbide, hammers and impact plate was a surprise, in contrast with no noticeable wear on the pellet mill contact surfaces.

When viewed under a scanning electron microscope (SEM), powder from the sieved, hammer-mill pan fraction, appeared more uniformly pulverized than the equivalent fraction from the pellet mill. Remnants of the glass fiber reinforcement were easily distinguishable from the polyurethane matrix in both fractions. Some residual cellular structure could be identified in the pellet-milled sample while no cellular structure was observed in the hammer-milled sample. The hammer mill, at 34 kg/h, was superior to the pellet mill at 29 kg/h, relative to material flow rate.

Grinding equipment for this recycling method is a function of many parameters including expected throughputs, wear rates, and desired efficiency. The testing shows that both grinding methods are suitable for this application.

6.6.3 LD-SRIM with recyclate content
This recycling process uses the addition of size-reduced LD-SRIM scrap to fresh polyol to produce new parts with recycled content. With this process, lance cylinder metering must be used to handle the filler content. In addition, a hardened mixhead and orifice are recommended. All testing used a commercial polyol blend as the base formulation.

A door panel simulation test attempted to evaluate the grinding of a complete door panel including the vinyl coverstock and flexible foam. Simulation was used as a substitute for obtaining a complete pulverized door panel. The flexible foam powder was created by first size reducing flexible foam seating in a knife mill followed by pulverizing in a pellet mill. Vinyl coverstock of a door pan-
el was simulated through the addition of drysol powder to the polyol blend. The drysol powder was the same powder used by an automotive molder to produce vinyl skins. For the door panel simulation, the pulverized flexible foam and drysol powder were added to the base polyol in percentages representative of a commercial door panel.

Representative material percentages were determined by evaluating two door panels currently in production at different molders. This evaluation showed that door panels could be molded in the following manner: substrate, 42-17%; flexible foam, 23-29%; and vinyl skin, 25-35%.

The recycle process was evaluated by molding plaques for physical properties, molding door panels to assess flow, and making bucket shots to evaluate effects of recycle on system reactivity, as seen in the representative molding parameters of Table 1. The temperature of the polyol blend with recycle was increased to reduce viscosity for improved mixing. The isocyanate temperature was lowered to maintain the same reaction profile.

There is not a significant change in system reactivity when the recycle is added, although the end or rise is slightly delayed. Free rise density decreased slightly with the added recycle. These changes can be eliminated easily with changes in the system catalyst package.

Filler does affect the cellular structure of the LD-SRIM. Average cell size of the filled system is larger than the unfilled system. This effect, however, did not significantly change the plaque’s physical properties. The molded 10%-filled system has some elongated cells and larger cells compared to the control.

In the molding of door panels, the recycle-filled system showed a slight reduction in flow, which is not significant for most molding applications. Although the flow was reduced slightly, high-quality panels were produced with good recycle distribution throughout the substrate.

There is no significant reduction in physical properties when the recycle is incorporated into the filler, as shown in Table 6.17. The recycle had no effect on the flexural modulus or strength. Tensile modulus showed some variation from the composite nature of the material, while tensile strength varied slightly between the control and recycle-filled samples. Consistent results were also observed in the heat deflection temperature data. The physical-property results conclusively illustrate

<table>
<thead>
<tr>
<th>Property</th>
<th>Control</th>
<th>10%-filler</th>
<th>Control</th>
<th>10%-filler</th>
<th>15%-filler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (µm)</td>
<td>0.45</td>
<td>0.47</td>
<td>0.55</td>
<td>0.57</td>
<td>0.51</td>
</tr>
<tr>
<td>Glass content (%)</td>
<td>18.8</td>
<td>21.6</td>
<td>17.8</td>
<td>18.1</td>
<td>21.2</td>
</tr>
<tr>
<td>Flexural modulus (MPa)</td>
<td>1060</td>
<td>970</td>
<td>1110</td>
<td>1110</td>
<td>1120</td>
</tr>
<tr>
<td>Flexural strength (MPa)</td>
<td>37</td>
<td>32</td>
<td>44</td>
<td>40</td>
<td>41</td>
</tr>
<tr>
<td>Tensile modulus (MPa)</td>
<td>1210</td>
<td>1130</td>
<td>1280</td>
<td>1430</td>
<td>1010</td>
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<tr>
<td>Tensile strength (MPa)</td>
<td>17</td>
<td>14</td>
<td>19</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>Instrumented impact strength</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max load (N)</td>
<td>866</td>
<td>791</td>
<td>890</td>
<td>721</td>
<td>844</td>
</tr>
<tr>
<td>E @ max load (J)</td>
<td>3.399</td>
<td>3.164</td>
<td>3.954</td>
<td>2.781</td>
<td>3.096</td>
</tr>
<tr>
<td>E after max load (J)</td>
<td>2.900</td>
<td>2.444</td>
<td>2.444</td>
<td>2.510</td>
<td>2.721</td>
</tr>
<tr>
<td>Total energy (J)</td>
<td>6.300</td>
<td>5.608</td>
<td>6.399</td>
<td>5.291</td>
<td>5.817</td>
</tr>
<tr>
<td>Heat deflection temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ 455 kPa (°C)</td>
<td>99.6</td>
<td>86.1</td>
<td>93.2</td>
<td>86.0</td>
<td>92.2</td>
</tr>
<tr>
<td>@ 1820 kPa (°C)</td>
<td>60.6</td>
<td>62.0</td>
<td>59.9</td>
<td>62.3</td>
<td>64.2</td>
</tr>
</tbody>
</table>

Filler % is on the system
that puvkerized parts can be added as filler to fresh LD-SRIM polyol as a viagle production method for recycling LD-SRIM.

6.7 Recycling of waste PVC leather and PVC urethane in the automobile industry

6.7.1 Decision to reutilize the waste

The waste PVC leather and PVC urethane is generally discharged as a mixture and cannot be reused in its existing state. Reutilization of waste as a resource must start from its separation into constituent materials. It is not too much to say that a successful separation reaches halfway to successful reutilization as a resource.

Examination of how wastes similar to ours (Fig. 6.14) are recycled in other industries showed that thick waste PVC leather discharged after the production of shoes and bags is separated into PVC grains and cloth by crushing and air classification, to reuse the PVC grains as a raw material for the product. By contrast, waste PVC leather and PVC urethane discharged from our plant comprises fragments generated in the production of car seats and interior products, and includes a large amount of thin cloth coated with thin PVC, most of which has urethane foam sewn together as a cushion. How to separate the mixture wastes efficiently into their constituent materials was a large problem, and ex-

Fig. 6.14 Kinds of wastes from seat production

Fig. 6.15 Recycling flow
amination started from this aspect. Concurrently, possible applications of recovered PVC and urethane were also examined, as described below.

In general, the principal difficulty in the reutilization of wastes is the difficulty of maintaining continuity. One of the reasons concerns profitability, but a more serious fact is that demand continually changes, depending on the situation for the users of processed wastes. Processed waste suppliers wish demand to continue, but this is difficult to achieve. Therefore, our plant decided to use the wastes for our automobile parts with the greatest importance attached to continuity.

Successful research and development for the preparation of automobile parts from the waste took place under the cooperation of a parts maker. In addition, an efficient air separation and recovery device was developed, and regular operation began from 1975. The recycling system has been used from that date, although the applied parts, and the share of processing, have changed. Fig. 6.15 shows the recycling flow (Miyama, 1987).

Table 6.18 Experimental results of crushing

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample</th>
<th>Crushed quantity (kg)</th>
<th>Period of time (min)</th>
<th>Crushing capability (kg hr⁻¹)</th>
<th>Crusher current (A)</th>
<th>Crushed state</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Waste PVC leather</td>
<td>17.0</td>
<td>8.0</td>
<td>127</td>
<td>20-30</td>
<td>Urethane pieces are too large</td>
</tr>
<tr>
<td></td>
<td>Waste PVC urethane</td>
<td>13.2</td>
<td>13.5</td>
<td>58.6</td>
<td>20-30</td>
<td>Separation from PVC is poor</td>
</tr>
<tr>
<td></td>
<td>Waste PVC leather</td>
<td>19.0</td>
<td>10.0</td>
<td>114</td>
<td>30-50</td>
<td>If urethane can be blown away when held in the land, than PVC can be easily separated</td>
</tr>
<tr>
<td>2</td>
<td>Waste PVC urethane</td>
<td>7.0</td>
<td>8.0</td>
<td>52.5</td>
<td>30-50</td>
<td>Cloth adheres to PVC</td>
</tr>
</tbody>
</table>

Fig. 6.16 Crushing test equipment
6.7.2 Examination of the method for separating materials

The wastes discharged from the shop include three types, as shown in Fig. 6.14. Of these, sewn three-layer articles (c) are generated in the largest quantities.

Waste is more than that, if it is not processed for separation into constituent materials. As for the methods for separating the constituent materials, for type (a), erosion of cloth by sulfuric acid is well known but has not been used practically for (b) and (c) as far as we know. It was therefore necessary to develop a new separation method.

Fig. 6.17 Materials separation and recovery equipment flow

Fig. 6.18 Breakdown of recovered materials
Table 6.19 Separation standard

<table>
<thead>
<tr>
<th>Recovered material</th>
<th>Form</th>
<th>Specific gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urethane Chips</td>
<td>To be crushed into 10-30 mm square pieces</td>
<td>Purchase raw material (urethane 100%) – 0.02</td>
</tr>
<tr>
<td></td>
<td>To contain less than about 30 wt % of PVC and cloth</td>
<td>Recovered material – 0.065</td>
</tr>
<tr>
<td>PVC Grains</td>
<td>To be grains of 1-3 mm (the cloth adhering to the back of PVC may remain attached)</td>
<td>Not to contain urethane</td>
</tr>
</tbody>
</table>

It was concluded that the most orthodox method, i.e. of ‘crushing and air separation’ would be the optimum, on the precondition that the recovered constituent materials are not changed in the material.

Fig. 6.19 Regions of applied parts (example)

(a) Molding of head rest and arm rest

Urethane chips 85%  
Worsted 10%  
Binder 2

Mixing → Mold filling → Hot press → Product

(b) Production of trunk mat

PVC grains 80%  
Brand new PVC 18  
Carbon black 2

Banbury mixing → Sheeting → Laminating → Punching → Product

Fig. 6.20 Parts production flow
Table 6.20 Processed tonnage and recovered tonnage

<table>
<thead>
<tr>
<th>Kind of waste</th>
<th>Input Kind of recovered material</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste PVC leather</td>
<td>465 Urethane chips</td>
<td>365t 437 t yr⁻¹</td>
</tr>
<tr>
<td>Waste urethane</td>
<td>t yr⁻¹ PVC grains</td>
<td>72 t 28 t yr⁻¹</td>
</tr>
<tr>
<td>Waste PVC urethane</td>
<td>Skin cloth (incinerated)</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.21 Annual processing cost

<table>
<thead>
<tr>
<th>Equipment investment</th>
<th>Depreciation 73.4 million yen</th>
<th>Tax, interest and insurance 16.9 million yen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Sub-total 17.6 million yen</td>
<td>Repair expenses 3.0 million yen</td>
</tr>
<tr>
<td></td>
<td>Electric power charge 3.4 million yen</td>
<td>Labor cost 10.8 million yen</td>
</tr>
<tr>
<td>Variable expenses</td>
<td>Sub-total 17.2 million yen</td>
<td>Total 34.8 million yen</td>
</tr>
</tbody>
</table>

Unit cost of processing = \( \frac{\text{Total processing cost}}{\text{Recovered quantity}} = \frac{34.8 \text{ million yen}}{437 \text{ t}} = 80 \text{ yen kg}^{-1} \)

Separation tests

Based on the above conclusion, it was decided to make preliminary tests for obtaining data for determining the specifications of machines.

(i) Samples.
(PVC film + cloth), glued (waste PVC leather).
(PVC film + cloth) + (urethane + cloth), sewn (waste PVC urethane).

Table 6.22 Amount of annual cost reduction, by material

<table>
<thead>
<tr>
<th>Material used</th>
<th>Product cost</th>
<th>Cost reduction per weight (1)</th>
<th>Annual consumption (2)</th>
<th>Annual cost reduction (1) x (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urethane</td>
<td>513 yen kg⁻¹</td>
<td>108 yen kg⁻¹</td>
<td>365.000 kg</td>
<td>39.4 million yen</td>
</tr>
<tr>
<td>PVC</td>
<td>105 yen kg⁻¹</td>
<td>72.000 kg</td>
<td></td>
<td>7.6 million yen</td>
</tr>
</tbody>
</table>

Overall effect
Total annual cost reduction (Table 6.22) – Total annual processing cost (Table 6.21) = Effect
47.0 million yen – 34.8 million yen = 12.2 million yen
(ii) **Crushing test equipment.** Fig. 6.15 shows the outline of the equipment. 
Crusher: rotary shear type, blade width 450 mm, with two fixed blades and five rotating blades, consumption 15 kW.
Exhaust fan: turbo type, 23 m³ min⁻¹, 95 mm Az, 0.75 kW.
Recovery cyclone: barrel 600 diameter.

(iii) **Experimental results.** As shown in Table 6.18, the recovery of urethane alone could be achieved by crushing only. However, the recovery of PVC required separation from the cloth, and it was found that actual operation required the additional use of a fine crusher.

6.7.3 Outline of the materials separation and recovery equipment
The following equipment was developed on the basis of the results of the above separation tests, considering workability, costs.
Fig. 6.17 shows the flowsheet.

**Process**
(i) Waste PVC leather and PVC urethane are put into a coarse crusher. Each piece should be about 300 mm square; larger pieces should be cut beforehand.
(ii) The coarse crusher comminutes to 10-30 mm square pieces, and allows them to fall onto a vibrating conveyor.
(iii) Air is sent from the underside of the vibrating conveyor, to agitate the crushed pieces.
(iv) Light urethane chips are recovered by suction nozzles.
(v) Heavy PVC is further crushed into 1 to 3 mm grains by fine crusher and recovered by a classifier.

**Breakdown of recovered materials**
The balance of the recovered materials is as in Fig. 6.18.

**States of recovered materials**
If the waste PVC leather and PVC urethane were separated more accurately into the respective constituent materials, they would find wider application, but on the other hand, at a higher cost. Compromise is inevitable in this respect.
This plant uses the separation standards shown in Table 6.19.

6.7.4 Selection of applicable automobile parts
The use of the processed waste for automobile parts is limited in application, and parts using the processed wastes should be the less-visible and less-functionally important. From this point of view, parts were examined by the value analysis technique, and the most suitable ones selected.

**Applied parts:**
Urethane chips: molded head rest and arm rest;
PVC grains: filler for trunk mat.
Fig. 6.19 shows the regions of the applied parts.

These parts were then molded, using the purchased raw materials only. As a matter of course, careful tests had been repeated by trial production for the parts, before regular production. The tests included:
(i) Sensory tests for resiliency, cushioning, etc.
(ii) Interlayer peeling tests between different materials.
(iii) Durability tests.
These tests were repeated to decide the optimum mixing ratios (the parts production flors is reported in Fig. 6.20).
6.7.5 Quality and costs of regenerated materials

Provided that automobile parts display their proper commercial functions, it is of no importance whether they are made of purchased materials or regenerated materials. In our case, there was the rather unexpected result that the regenerated materials were better. For example, when a conventional product of urethane (100% purchased) needs a certain hardness, aggregate has to be added as required. However, the mixing of the regenerated material provides the proper hardness, eliminating the need for adding aggregate. As a considerable side effect, the cushioning property can be freely changed by changing the mixing ratio.

The actual statistics in this plant were as given below.
(i) Processed tonnage and recovered tonnage are listed in Table 6.20.
(ii) Annual processing costs are listed in Table 6.21.
(iii) Annual cost reduction, by material, are listed in Table 6.22.

The overall effect is (Total annual cost reduction) - (Total annual processing cost). Our plant achieves an annual positive effect of about 12.2 million yen. Including the expenses for land reclamation executed in the past, the effect corresponds to about 40 million yen.

As described above, the reutilization of wastes in the plant began from the necessity of taking measures to prevent pollution; however, waste is now indispensably required as a raw material.

The system is not, however, problem-free. In the past decade, the seats have been enhanced in quality, a drastic reduction in the use of PVC, and the use of woven fabric which is difficult to recycle, is increasing. In addition, the cost of solid moldings, using no regenerated material, has declined, causing severe competition with the regenerated materials. The reutilization of wastes as resources is not always simple.

The recycling of wastes as a resource is always confronted by such difficulties. This case has the advantage that the regenerated materials are used for mass-produced motor vehicles, which provide a continuous demand.

6.8 Cost simulation of the Automobile Recycling Infrastructure: the Impact of Plastics Recovery

6.8.1 A New auto recycling challenge

In the current automobile recycling infrastructure, plastics are not recovered to any significant degree. This fact, combined with the visibility of the automobile and the presence of plastics in packaging waste, has elevated automotive plastics on the list of environmental concerns. Whether or not this position is deserved is discussed in the conclusion. Regardless, the automotive and plastics industries have joined forces to address the recovery of plastics. At the heart of the issue are the costs of recycling plastics and their resulting values. To resolve the issue, these costs must be understood.

This point examines the costs and values associated with the present automobile recycling infrastructure using a technique called Technical Cost Modeling. These values result from metal recovery, while the costs are from processing and ASR landfilling. Four plastic recycling options are forwarded as alternatives to the present practice (Dieffenbach et al., 1993).

- Plastics dismantling
- Bulk separation
- Incineration
- Pyrolysis

The costs of these are simulated using the modeling approach. Furthermore, each is assessed in terms of what must happen to improve its effectiveness, and by how much. Before examining the materials in today’s automobile and the resulting costs and values of recycling, Technical Cost Modeling of the automobile recycling infrastructure is introduced.
6.8.2 Technical cost modeling

Technical Cost Modeling is a computer spreadsheet technique used by IBIS Associates for the simulation of process costs. In a Technical Cost Model (TCM), cost is assigned to each unit operation in a process flow diagram. Costs are summarized corresponding to unit operations, each representing a single machine or station with an associated production rate. Each station is characterized by factors including number of laborers, equipment and tooling costs, and other investment and operating costs.

Technical Cost Models can be used to accomplish tasks that include the following:
- Simulate the costs of manufacturing products
- Establish direct comparisons between material, process, and design alternatives
- Investigate the effect of changes in the process scenario on overall costs
- Identify limiting process steps and parameters
- Determine the merits of specific process and design improvements.

Technical Cost Modeling is implemented on a computer spreadsheet such as Lotus 1-2-3 or Microsoft Excel. The power and flexibility of using a computer spreadsheet facilitates rapid data storage, data manipulation, and output recalculation.

The automobile recycling TCM is based on the automobile recycling infrastructure of dismantling, shredding/ferrous metal separation, non-ferrous metal separation, and disposal. The foundation of the model is the tracking of the flow of materials throughout the various stages of the recycling infrastructure, beginning with the scrapped vehicle. Based on this flow, the cost of each operation is broken down into the elements listed below:
- Material revenue
- Material cost
- Total operating cost
- Total investment cost
- Operation value added
- Total operation cost
- Operation net profit

Material revenue results from selling parts, hulks, scrap materials, and energy. Material cost results from purchasing these items as well as input vehicles. Operating costs are variable costs exclusive of materials. Investment costs are allocated based on throughput over facility lifetime to generate the cost per vehicle. Operation value added is the sum of operating and investment cost per vehicle. Total operation cost is the sum of value added and material cost. Operation net profit is the ratio of the difference between material revenue and total operation cost to the material revenue.

The model allows for the consideration of different case study scenarios through the adjustment of input assumptions. Case studies can include vehicle material mixes, production volumes, and operation efficiencies. Based on the input assumptions, the model tracks the material flow through each of the operations, tallying up material, operating, and investment costs.

6.8.3 The present infrastructure

As outlined previously, the present automobile recycling infrastructure consists of three stages.
- Dismantling
- Shredding/ferrous separation
- Non-ferrous separation

Each of these stages sends waste, including plastics, to landfill.

ASSUMPTION: The key assumptions used in the model for each of the above operations are presented in Model List 1, along with any general or global assumptions. The cost analysis includes fees to buy vehicles and sell materials, internal transfer costs for hulks and material streams, transportation costs, and landfill costs. The analysis does not include any intermediary brokers or the fees that
they charge. Inclusion of these brokers will affect the profit margins of the individual operations, but will not affect the overall cost and value of the post-use vehicle.

**COSTS:** Model Lists 2, 3, and 4 show the cost summaries for each of the three operations. An overall summary is shown in Model List 5 Fig. 6.21 shows how the profit margins of the three operations change with varying landfill tipping fee. It can be seen that non-ferrous separation becomes unprofitable first with increasing landfill tipping fee. In fact, all three operations remain profitable for foreseeable landfill costs relative to the average of $25 per metric ton paid in the U.S. today.

6.8.4 The plastics recovery alternatives

As previously defined, four plastics recycling alternatives are analyzed: plastics dismantling, bulk separation, incineration, and pyrolysis. These are discussed below.

**ASSUMPTIONS:** The assumptions for the four plastic recovery options are shown in Model List 6. Plastics dismantling consists of the hand removal of plastic components from the vehicle. “Bulk separation” represents a “black-box” technology capable of separating and cleaning plastics from ASR. The particular technology, or whether or not it exists at this time, is not important for the analysis; it might range from a labor intensive “manual” sort to a large scale solvent separation, or some-

---

**Post-use Analysis Input Assumptions**

<table>
<thead>
<tr>
<th>POST-USE ASSUMPTIONS</th>
<th>Dist</th>
<th>General</th>
<th>Shred</th>
<th>Non-Fe</th>
<th>Food-</th>
<th>Land-</th>
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</thead>
<tbody>
<tr>
<td>Transport ($/velt)</td>
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<td></td>
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</tr>
<tr>
<td>Tip Fee</td>
<td>$50</td>
<td>$50</td>
<td>$1.00</td>
<td>$50</td>
<td>$33</td>
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<tr>
<td>/car /bulk /pct /ton</td>
<td>/ton</td>
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<td>Capacity</td>
<td>3,000</td>
<td>40</td>
<td>600,000</td>
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<tr>
<td>Capacity units</td>
<td>care/yr</td>
<td>tons/hr</td>
<td>kg/day tons/day</td>
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<td></td>
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</tr>
<tr>
<td>Dismantle (hr/pct)</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Op Cost ($)</td>
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<tr>
<td>Salary ($)</td>
<td>$40,000</td>
<td>$40,000</td>
<td>$40,000</td>
<td>$40,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Staff</td>
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<td>2</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model List 1

---

**Dismantling Cost Summary**

<table>
<thead>
<tr>
<th>AUTOMOTIVE RECYCLING TON: DISMANTLING COST SUMMARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRIS ASSOCIATES, INC. v.1.0</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$/ton</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>MATERIAL COST</td>
</tr>
<tr>
<td>MATERIAL COST</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Labor Cost</td>
</tr>
<tr>
<td>Other Operating</td>
</tr>
<tr>
<td>Plastic Operating</td>
</tr>
<tr>
<td>TOTAL OPERATING COST</td>
</tr>
<tr>
<td>Investment Cost</td>
</tr>
<tr>
<td>Plastic Investment</td>
</tr>
<tr>
<td>TOTAL INVESTMENT COST</td>
</tr>
<tr>
<td>TOTAL VALUE ADDED</td>
</tr>
<tr>
<td>TOTAL OPERATING COST</td>
</tr>
<tr>
<td>OPERATION NET PROFIT</td>
</tr>
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</table>

Model List 2
## Shred/Ferrous Separation Cost Summary

<table>
<thead>
<tr>
<th>Material Revenue</th>
<th>Material Cost</th>
<th>Value %</th>
<th>$/Vehicle</th>
<th>$/Ton</th>
<th>$/Year Percent</th>
<th>$/Invest</th>
</tr>
</thead>
<tbody>
<tr>
<td>$135.85</td>
<td>$75.70</td>
<td>70.4%</td>
<td>$4.28</td>
<td>$4.42</td>
<td>5.4%</td>
<td>$12.90</td>
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</tbody>
</table>

## Non-ferrous Separation Cost Summary

<table>
<thead>
<tr>
<th>Material Revenue</th>
<th>Material Cost</th>
<th>Value %</th>
<th>$/Vehicle</th>
<th>$/Ton</th>
<th>$/Year Percent</th>
<th>$/Invest</th>
</tr>
</thead>
<tbody>
<tr>
<td>$185.22</td>
<td>$19.55</td>
<td>82.4%</td>
<td>$3.38</td>
<td>$1.26</td>
<td>7.7%</td>
<td>$34.00</td>
</tr>
</tbody>
</table>

## Overall Cost Summary

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Value</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>$420.70</td>
<td>$122.89</td>
</tr>
</tbody>
</table>

## Model List

Model List 3

Model List 4

Model List 5
where in between. The exercise of running a cost analysis requires only throughput, labor, and investment assumptions. These assumptions can then be varied to determine the conditions under which an operation, even a generic or future one, might be profitable.

For the sake of this analysis, it is assumed that the bulk separation process is at the non-ferrous separation facility, and that both the Heavy and Light fractions are delivered from the shredder. In actuality, it is likely that the bulk separation process would be integrated with either or both operations. From a cost analysis standpoint, the economics will be similar.

Incineration is the burning of ASR in a conventional municipal incinerator. Pyrolysis is the chemical decomposition of ASR via the application of heat in the absence of oxygen. Pyrolysis has been demonstrated at the pilot scale level, but is not in operation as a full scale process (Cucuras 1991; Hartt and Carey, 1992). For both incineration and pyrolysis, any non-combustible or non-convertible portions of the ASR will be landfilled as ash.

**PLASTICS DISMANTLING COSTS:** Fig. 6.22 shows how the profitability of plastics dismantling is a function of added plastic recovery times. The horizontal line represents the present, no plastic recovery, “baseline” profit margin. The different curves represent two material price scenarios. In the

![Graph showing profit margin with varying landfill tipping fee](image)

**Fig. 6.21** Profit Margin of the three operations with varying landfill tipping fee

---

### Plastic Recovery Assumptions

<table>
<thead>
<tr>
<th>Plastic Recovery Specifications</th>
<th>Dismantling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Added Plastic Dismantling Time</td>
<td>0.5 hrs/ton</td>
</tr>
<tr>
<td>Plastic Dismantling Efficiency</td>
<td>60.0%</td>
</tr>
</tbody>
</table>

**Bulk Separation**

| Bulk Sep’s Operating Cost      | $300,000    |
| Bulk Sep’s Investment Cost     | $20,000,000 |
| Plastic Sep’s Efficiency       | 60.0%       |

**Incineration**

| Incinerator Tipping Fee        | $500/ton   |
| Ash Disposal Fee               | $300/ton   |
| Rated Facility Capacity        | 1,500 m tons/yr |
| Operating Cost                 | $19.20/ton |
| Investment Cost                | $154,000,000 |

**Pyrolysis**

| Pyrolysis Tipping Fee          | $90/ton |
| Rated Facility Capacity        | 1 ton/hr |
| Operating Cost                 | $25/ton |
| Investment Cost                | $2,300,000 |
| Pyro Oil Price                 | $0.07/liter |

---

*Model List 6*
first scenario, for the lowest curve, plastics are assumed to have a scrap value that can be obtained in a market today. This is the “Today” scenario. In the second scenario, for the remaining curves, all plastics are assumed to have a scrap value of a fixed percentage \( P \) of the virgin resin price. These are the “Future P%” scenarios.

Assuming that the Dismantler will need to be at least as profitable as the baseline case for plastics dismantling as the baseline case for plastics dismantling to occur, the intersection of a scenario curve with the baseline profit margin line represents a maximum added recovery time to remove the specified 60 percent plastic (Model List 6). For instance, following the Today scenario curve to the intersection with the baseline case indicates that 60 percent of the plastic must be removed in under 0.5 hours to be profitable. For times longer than this, the Dismantler will not be as profitable, and would therefore elect not to recover the plastic.

Fig. 6.22 Profit Margin of plastics dismantling as a function of added plastic removal times

Fig. 6.23 Profit Margin of Non-Ferrous Separator as a function of added Bulk Separation Investment
**BULK SEPARATION COSTS:** Fig. 6.23 presents the profitability of the Non-Ferrous Separator as a function of added bulk separation investment. The horizontal line again represents the baseline profit margin. The various curves are for three throughputs each at both the Today and Future 50 percent (of virgin) scenarios. For a given material scrap price scenario, the intersection of an investment cost with the baseline profit margin line represents a minimum throughput for the added bulk separation operation to be profitable relative to the existing operation. As an example, the curve for T2 shows that bulk separation can be profitable if 5,000 kg/hour can be achieved with an investment of less than approximately $7 million.

**INCINERATION COSTS:** For conventional municipal solid waste (MSW) incineration to be viable for ASR, it is necessary for the ASR to be free of hazardous contaminants. Otherwise, the ASR would have to undergo costly hazardous waste incineration. This distinction merits a brief digression on the makeup of ASR.

ASR contains all of the materials that are used to manufacture the automobile (including the metals, which are not recovered with 100% efficiency). Today’s automobile is made from a relatively inert, environmentally harmless combination of materials. Primary exceptions are some fluids, including gasoline and oil, as well as heavy metals such as cadmium and lead. All of these can be (and in most cases are) removed from the vehicle at the dismantling stage.

Some of the most significant actual contaminants of ASR are PCBs, which are introduced through the shredding of appliances and other capacitor containing products. While these PCBs are certainly an issue, the burden of handling them should not fall solely or even primarily on the auto industry. Because of its plastic content, ASR is not only relatively safe (with proper precautions), but also energy intensive as an incineration fuel.

Model List 7 presents the cost summary for a typical incinerator operating with ASR recovery, based on the assumptions presented in Model List 6. Figure 6.24 shows how the profitability of an incineration operation changes with a varying tipping fee. The horizontal line represents the baseline profitability of an incinerator at today’s average incineration tip fee of $50 per metric ton. The curve represents the variability of this profit margin with changing tipping fees. The figure indicates that burning ASR can be profitable. Of course, it is necessary to pay a higher tipping fee than that charged by landfill; an increase in average landfill tipping fees is necessary for incineration to be preferred solely from a cost standpoint. From Fig. 6.24, it is shown that an incinerator can profitably burn ASR for a tipping fee under $20. The exact tipping fee at which the incinerator makes a profit relative to the MSW business depends on the MSW profit margin.

![Graph showing the profit margin of an incineration operation with a varying tipping fee](image-url)

*Fig. 6.24 Profit Margin of an incineration operation with a varying tipping fee*
PYROLYSIS COSTS: Pyrolysis is a potentially valuable recycling process because it reduces the flow of material to landfill, and because it recovers materials that have potential value: pyro-oil, pyro-gas, and solid by-products, or “char”. The pyro-oil can be sold as fuel (Model List 6), while the pyro-gas is consumed in the process itself. The char has potential value as a filler material, although it might also be landfilled. Given these recovery values, the economic viability therefore rests on the cost of the process.

Because pyrolysis has not been demonstrated in large scale, its economics are less well understood. As with the bulk separation case, its profitability is a function of several key factors. For pyrolysis, there are tip fee, operating cost, investment cost, and throughput.

Model List 8 shows the cost summary for the pyrolysis operation based on the assumptions presented in Model List 6. Fig. 6.25 shows how the profitability of the pyrolysis operation changes with varying tipping fee for a number of process assumptions. The horizontal line represents the conservative baseline operation (slow throughput, low operating cost, low investment cost). The remaining

![Pyrolysis Cost Summary Table](image)

Model List 8

![Pyrolysis Operation Graph](image)

Fig. 6.25 Profit Margin of the pyrolysis operation with varying tipping fee for a number of process assumptions
curves represent the profit margins for hypothetical scaled-up scenarios. The particulars of the following scenarios are presented in the figure legend:

- Fast throughput, moderate operating cost, high investment cost
- Medium throughput, moderate operating cost, high investment cost
- Medium throughput, high operating cost, moderate investment cost
- Slow throughput, high operating cost, low investment cost.

From the curves in Fig. 6.25, it can be seen that scenarios S1 and S3 result in a profitable operation at tipping fees approaching those of today’s landfill. Scenario S2 become profitable at a tipping fee of about $55 per metric ton.

The analysis presented above is based on a large number of assumptions. This paper concludes with a discussion of how changes in these assumptions can affect the analysis and how the analysis can be used to assist in decision making. It is clear from the analysis, however, that plastics recovery can be profitable under the right conditions should landfill be deemed unacceptable.

The use of both the present and future plastic recovery recycling infrastructures assumes a legislative and regulatory environment. An excellent treatment of these issues can be found elsewhere (Dickey, 1992). As this environment changes, perhaps following Europe, Japan, or an entirely new approach, so too will the analysis. The need to rework the analysis highlights the need for a flexible tool.

The analysis will similarly be altered if a different measure is used. Profitability is selected here, although other measures such as revenue (equivalent to market share) could certainly be used. While the overall results will not be altered, the relative competition between specific options can be modified depending on the measurement scheme. Again, a flexible tool makes such changes easy.

The present industry line is to argue against landfilling. This cannot be done in a vacuum, however. Economic cost must certainly also be considered, as these costs represent at least a snapshot of what markets are willing to pay. An environmental argument against the landfilling of a material cannot be made without examining the other environmental benefits of the material being landfilled. In the case of automotive plastics, for instance, it can easily be shown that the fuel cost and accompanying emissions saved via lightweighting far outweigh the cost of landfilling.

Finally, the process specific assumptions used in the preceding analysis are critical to the costs the model generates. In the end, cost and performance issues must compete with environmental impact as inputs to the strategic decision making process. Without a platform to understand cost and performance measures, this process cannot be complete.
Chapter 7
Design for Aluminium Recycling

7.1 Introduction

Today's automobiles challenge designers to an unprecedented degree. As always, the designer must provide safe, comfortable, reliable, and stylish transportation at a reasonable price to the customer and a reasonable profit to the automaker. Society today, though, adds requirements for fuel efficiency and benign environmental influences.

Aluminium is playing an increasing role in automotive design. While downsizing accounts for much of the average car's weight reduction, aluminium use has significantly increased as well, as seen in Fig. 7.1. A recent survey determined that the average aluminium content of North American-built cars is 85 kg. Another survey reported similar results for 1990 Japanese-built models.

Forecasts consistently predict rising aluminium usage as weight reduction programs continue. The largest increase in demand for wrought product will take place as designers convert automotive body structures to aluminium. The prospect of such large-volume applications emphasizes the need to "close the recycling loop". A closed-loop system ensures into new wrought products, and benefits further growth of aluminium applications by assuring an economical, high-quality source of metal.

Public concern about unsightly junked cars in the 1960s is responsible in part for the effective auto recycling infrastructure in place today. Developments of electric-arc melting and automotive shredding make it profitable to recycle automotive steel. Improved segregating techniques separate nonferrous metals from the scrap stream to create a recycling loop for these materials as well.

The current recycling infrastructure shreds the entire car, creating a fraction of nonferrous metals as a byproduct of the steel recovery process. Further processing of the nonferrous fraction separates the various metals. Estimates place recovered aluminium content at 85%. Aluminium from the shredder process is an important feed-product for the castings industry, but has reduced value compared to segregated wrought aluminium alloy scrap ($0.22-0.33/kg less). This use of wrought scrap for castings may be thought of as "open loop" in contrast to the more desirable "closed loop". The difference is illustrated schematically in Fig. 7.2.
7.2 Application of aluminium to body structures

Weight reduction is an important factor for improvements in automotive fuel efficiency. The Environmental Protection Agency estimates that, in an automobile, 0.075 mL of gasoline can transport one kilogram a distance of one kilometer. Weight reduction affects about 65% of that consumption. Over 150,000 km, a weight saving of 100 kg will reduce fuel consumption by 736 L.

Three approaches to manufacturing aluminium body structures, in response to further reductions in fuel consumption, have different impacts on structural performance, economics, and recycling.

*Sheet structure:* Concepts developed during the 1980s use aluminium sheet in much the same processes as those used to make a stamped-steel body structure. The Acura NSX is an example of this aluminium sheet body structure in a low-volume, high-performance sports car.

*Space frame:* The use of aluminium extrusions to form a rigid, energy-absorbing structure to which body panels are attached is known as the space frame manufacturing approach. The extrusions may be joined by a variety of techniques. Body panels may be aluminium or plastic.

*Hybrid structures:* This approach combines features from the sheet and space frame techniques to maximize advantages of the individual techniques in a lightweight aluminium body structure. Thus a hybrid body structure may have castings, sheet, and extrusions intimately joined in the production process. Experts see hybrid structures becoming more common, with refinements based on field experience, and with improved process (Automotive Engineering, 1993).

7.3 Recycling of aluminium-intensive vehicles

In considering the impacts of manufacturing processes and alloy selection on recycling, three general factors must be recognized.

- Many different aluminium alloys and products are available, for, or currently used in, automotive applications.

Table 7.1 shows typical applications for various alloys. Most sources suggest that about 80% of the aluminium content is in castings, with wrought forms making up the remainder. These estimates assume that aluminium wheels are castings. Most cast alloys use significant amounts of old scrap in their manufacture, with up to 100% in alloy 380, and as much as 75% in alloy 356. When these figures are applied to the product mix, 50 to 60% of the aluminium in a car has been recycled from old scrap.

Fig. 7.2 “Open” vs “closed” loop recycling
### Table 7.1 Some Typical Aluminium Uses on U.S. Automobiles

<table>
<thead>
<tr>
<th>Part</th>
<th>Product Form</th>
<th>Alloy Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder head</td>
<td>Sand, permanent mold (PM) casting</td>
<td>356, 319</td>
</tr>
<tr>
<td>Intake manifold</td>
<td>Sand, PM casting</td>
<td>356, 319</td>
</tr>
<tr>
<td>Engine block</td>
<td>Sand, die casting</td>
<td>390, 319, 380</td>
</tr>
<tr>
<td>Water pump</td>
<td>Die casting</td>
<td>413, 380</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>Die, PM casting</td>
<td>332, A390</td>
</tr>
<tr>
<td>Brake part</td>
<td>PM casting</td>
<td>356</td>
</tr>
<tr>
<td>Transmission</td>
<td>Die casting</td>
<td>380, 383</td>
</tr>
<tr>
<td>Oil pump</td>
<td>Die casting</td>
<td>380, 383</td>
</tr>
<tr>
<td>Piston</td>
<td>PM casting</td>
<td>322, 336, 339</td>
</tr>
<tr>
<td>Wheel</td>
<td>Various casting processes</td>
<td>A356, A413</td>
</tr>
<tr>
<td>Wheel</td>
<td>Sheet, forging</td>
<td>6061, 5454</td>
</tr>
<tr>
<td>Bumper</td>
<td>Sheet, extrusion</td>
<td>6061, 7029, 7003</td>
</tr>
<tr>
<td>Trim</td>
<td>Sheet</td>
<td>5252, 5X57</td>
</tr>
<tr>
<td>Heat exchanger</td>
<td>Sheet, foil</td>
<td>3003, 1100, 7072</td>
</tr>
<tr>
<td>Outer body panel</td>
<td>Sheet</td>
<td>5XXX, 6XXX, 2XXX</td>
</tr>
<tr>
<td>Heat shield</td>
<td>Sheet</td>
<td>5XXX</td>
</tr>
<tr>
<td>Suspension part</td>
<td>Forging</td>
<td>6061</td>
</tr>
</tbody>
</table>

Alloy composition must be tightly controlled to ensure consistent properties and performance in components. This may result, however, in limited compatibility with the alloys to which it is joined. The degree to which these compositions are similar or different will determine the recyclability of the scrap mixture. Example compositions for automotive alloys is listed in Table 7.2.

### Table 7.2 Typical Alloy Compositions for Automotive Alloys

<table>
<thead>
<tr>
<th></th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sheet Alloys</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>0.65</td>
<td>0.20</td>
<td>0.95</td>
<td>0.06</td>
<td>0.35</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>2036</td>
<td>0.33</td>
<td>0.30</td>
<td>2.50</td>
<td>0.25</td>
<td>0.50</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>5052</td>
<td>0.15</td>
<td>0.27</td>
<td>0.04</td>
<td>0.06</td>
<td>2.53</td>
<td>0.21</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>5182</td>
<td>0.12</td>
<td>0.25</td>
<td>0.05</td>
<td>0.35</td>
<td>4.50</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>5030</td>
<td>0.10</td>
<td>0.08</td>
<td>0.30</td>
<td>0.02</td>
<td>4.50</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>6099</td>
<td>0.75</td>
<td>0.25</td>
<td>0.35</td>
<td>0.35</td>
<td>0.50</td>
<td>0.02</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>6061</td>
<td>0.60</td>
<td>0.30</td>
<td>0.25</td>
<td>0.10</td>
<td>1.00</td>
<td>0.18</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>6111</td>
<td>0.80</td>
<td>0.25</td>
<td>0.35</td>
<td>0.20</td>
<td>0.06</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>6016</td>
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<td>0.08</td>
<td>0.07</td>
<td>0.40</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Casting Alloys</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A356</td>
<td>7.00</td>
<td>0.60</td>
<td>0.25</td>
<td>0.35</td>
<td>0.30</td>
<td>0.05</td>
<td>0.35</td>
<td>0.05</td>
</tr>
<tr>
<td>A380</td>
<td>8.50</td>
<td>0.70</td>
<td>1.10</td>
<td>0.45</td>
<td>0.10</td>
<td>0.05</td>
<td>2.00</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Extrusion Alloys</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6X63</td>
<td>0.50</td>
<td>0.20</td>
<td>0.20</td>
<td>0.05</td>
<td>0.50</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>7005</td>
<td>0.20</td>
<td>0.25</td>
<td>0.06</td>
<td>0.45</td>
<td>1.40</td>
<td>0.13</td>
<td>4.50</td>
<td>0.03</td>
</tr>
</tbody>
</table>

- The mix of aluminium materials used will change with time.

Aluminium alloys used for outer panels have changed from 1972 to 1992, as seen in Table 7.3. This material development is likely to continue. Aluminium reclaimed from cars in 2003 will differ from the alloy mix seen by recyclers today. As body structure applications grow, a similar evolution is expected. Some of the outer panel alloys may find applications in the body structure, and needs for corrosion resistance and formability may drive significant development of 5XXX alloys.

- Any recycling process must effectively separate aluminium from other materials used in automobile manufacture.
Table 7.3 Aluminium Alloys for Outer Automotive Panels

<table>
<thead>
<tr>
<th>Year</th>
<th>Alloys</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>X5020, X2036, 6151, X5085, 6061</td>
</tr>
<tr>
<td>1982</td>
<td>2036, 5182, 6009, 6010</td>
</tr>
</tbody>
</table>

Removal of non-aluminium metal contaminants is a major recycling issue for all body structure techniques. Amounts of Fe greater than 0.5% make the alloy unacceptable except for the lowest grade of cast product. Wrought alloys with maximum Fe content in the 0.15-0.40 wt% range cannot absorb appreciable scrap with high Fe content. An addition of 500 g Fe to 50 kg Al results in total Fe contents well outside the desired range. This makes a reliable means of eliminating Fe as an impurity a necessary feature of any recycling process.

Contamination by other elements such as Cd, Bi, or Pb is unacceptable in closed-loop aluminium scrap. These elements cause undesirable metallurgical characteristics at levels less than 0.1%. However, the most pressing reason for their elimination is environmental. Workers in molten-metal recycling facilities are at risk to toxic exposures when these elements are in the recycling stream.

7.4 Recycling implications

Ideally for recycling, the entire car would use a single alloy. The other extreme pursues development of technology to separate, absolutely, each alloy piece from every other one. Many recycling scenarios exist along a cost-benefit curve between the extremes of single alloy specification and perfect alloy separation. These technological options must be judged by the question: is the cost of introducing technology to close the scrap loop offset by the higher value of the segregated material?

Technology undoubtedly will be developed to help capture higher value for aluminium automotive scrap. However, opportunities to take advantage of aluminium’s inherent value, and at least partially close the recycling loop, are possible without advanced technology.

The most important opportunity is in aluminium alloy selection. Aluminium suppliers and designers must work together to identify alloy compatibility problems before materials are specified. While all problems cannot be resolved, many may be reduced by design with recycling in mind. As an example, the same alloy should be used for connected panels.

For assemblies for which economical dismantling is possible (e.g., hoods and deck lids), the use of one alloy creates the incentive for removal from the hulk before shredding. Large, single-alloy components, such as bumpers or castings, also may facilitate a partial dismantling scheme. Marking each assembly with an alloy ID code (similar to the method for recycling plastics) would be useful in this process scheme.

After partial dismantling, shredded aluminium needs further processing to realize its potential value. For cases in which alloys of a similar family are used, separation into “classified scrap” categories may be possible. The classified scrap could encompass all alloys of the same family or be segregated to a higher degree if the technology becomes available.

For instance, were all 6XXX alloy scrap (extrusions and sheet) on the car segregated, it would have enhanced value compared to mixed 2XXX/5XXX/6XXX wrought scrap. Again, alloy selection becomes important as the presence of absence of Cr influences the value of the scrap.

Aluminium processors for this alloy-segregated or classified old scrap must adjust their processes to use it effectively in closing the recycling loop. Removal of paints and adhesives will be necessary, using the same technology now employed for used beverage containers.

Sheet-panel body structure is the simplest to handle from a product point of view, but it presents some special challenges for recycling. The major issue is the compatibility of the body structure al-
loys with each other and with the outer panel alloys to which they are joined. Body structure alloys require high formability and corrosion resistance with only modest strength. These needs are best met in current designs by various 5XXX alloys. Alloys for the outer panels need formability during stamping and high strength after the paint bake. Present industry practice has no universally accepted alloy for outer panels.

Body structure alloy 5182 has limited absorption into other sheet alloys. While some outer panel alloys vary only slightly in composition within alloy families, none are 100% compatible from an absorption standpoint. Table 7.4 shows this recycling compatibility.

**Table 7.4 Recycling Compatibility of Various Aluminium Sheet Alloys**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>2008 (Cu)</th>
<th>6111 (Mn)</th>
<th>6009 (Cu)</th>
<th>2036 (Cu)</th>
<th>5182 (Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>100</td>
<td>88.8</td>
<td>43.8</td>
<td>53.1</td>
<td>4.3</td>
</tr>
<tr>
<td>6111</td>
<td>58.3 (Mn)</td>
<td>100</td>
<td>49.4 (Cu)</td>
<td>46.0 (Si)</td>
<td>5.4 (Cu, Si)</td>
</tr>
<tr>
<td>6009</td>
<td>31.8 (Mn)</td>
<td>54.5 (Mn)</td>
<td>100</td>
<td>49.3 (Si)</td>
<td>5.8 (Si)</td>
</tr>
<tr>
<td>2036</td>
<td>35.7 (Cu)</td>
<td>31.7 (Cu)</td>
<td>15.7 (Cu)</td>
<td>100</td>
<td>1.6 (Cu)</td>
</tr>
<tr>
<td>5182</td>
<td>7.6 (Mg)</td>
<td>13.1 (Mg)</td>
<td>10.9 (Mg)</td>
<td>10.9 (Mg)</td>
<td>100</td>
</tr>
</tbody>
</table>

Absorption in %

(Cu) = Copper  
(Si) = Silicon  
(Mn) = Manganese  
(Mg) = Magnesium

Significant problems arise when the 5XXX alloy scrap is mixed with 2XXX or 6XXX outer panel materials. Resultant mixtures have potential use only as cast products. Looking at Fig. 7.3, high Si or Cu in the 2XXX/6XXX alloys makes them unsuitable for absorption into the 5XXX alloys. The high Mg in the 5XXX alloys severely limits absorption into the other alloys.

Alloys containing Cr, such as 5052 and 6061, pose another barrier to recycling of all-sheet body structures. Mixed scrap from these alloys will have virtually no absorption into alloys such as 6009, 6111, or 5182. Thus designers must consider total alloy composition, not just the major alloying elements, in planning compatibility for recycling.

For the sheet body structure/outer panel recycling loop, a possible process parallels recycling within the aluminium beverage can industry. The body structure and outer panels, though two different alloys, have a high degree of compatibility. When melted together, the mixture can be readily absorbed back into the body structure alloy. Lower strength requirements in the body structure could accept higher impurities without degrading formability. This scheme also creates a classified grade of scrap and closes the loop since the primary aluminium producer becomes the major user of this scrap.

Extrusions in a space frame structure do not present any unusual recycling issues. However, if a space frame has aluminium sheet outer panels and castings for nodes, recycling of this multi-alloy structure will require special consideration. Sheet/extrusion compatibility issues are similar to those of 6XXX outer panel alloys. Extrusion alloy cannot accept much scrap, but scrap is acceptable in any of the non-5XXX sheet alloys.

Castings that are typically high in Si provide an absorption challenge. In Fig. 7.4, less than 10% of these cast alloys by weight severely limits absorption of a mixture into alloys such as 6009 or 2008. To close the recycling loop for space frame structures, technologies to eliminate the castings, either by disassembly, shredding, and classification, or differential melting must be employed.

Desirable recycling techniques for space frames handle castings in a closed-loop fashion. Current limits for some cast alloys severely limit Mg and Cr in absorbed scrap. Mg or Zn contamination is possible when recycling cast nodes to which 6XXX or 7XXX piece may still be attached. Universal-
ly accepted composition limits for cast alloys, that reflect product performance requirements, will improve the industry’s ability to close this portion of the recycling loop.

Recycling of hybrid structures, with their diverse material mixes, will most likely parallel closely those of space frame structures.

Adaptations within the existing recycling infrastructure will handle the expected increased volumes of aluminium scrap for the near term. Most importantly, consideration of recycling issues during aluminium alloy selection can simplify requirements placed on recycling process technology and can increase the value of scrap from aluminium-intensive vehicles.

Fig. 7.3 Scrap compatibility of selected aluminium sheet alloys

Fig. 7.4 Tolerance of alloys 6009 and 2008 for absorption of casting during recycling
Chapter 8
Recycling of Thermoplastic Elastomers in the Automotive Industry

8.1 Options for TPEs

Rubber, which has been a mainstay of the mobile society for over a hundred years, and TPEs, which have been more successful in the construction sectors for the last twentyfive years, have lately been meeting in vehicle construction. Here is the salient distinguishing mark: Whereas TPEs can be processed and converted in shape thermoplastically, rubber - after supply of crosslinking activation energy in the irreversible condition - does not lend itself to useful material transformations.

In practical linguistic usage, the TPEs cover a fairly heterogeneous field of polymer and control of application-relevant characteristics. A describing classification has been given by Hofmann (1). Certain centres of emphasis are as follows:
- The more rigid TPEs, which are improved versions of engineering plastics, as engineering elastomers, on the one hand,
- the more flexible multipurpose TPEs, e.g. the styrene block copolymers, on the other hand.

The considerations about automobile recycling increasingly tend towards the thermoplastic elastomer materials which are characterized by a large application and combination scope, a variety of components and good ageing resistance (Wiesbaden, 1993).

Suitability for road service, which is the predominant assessment criterion for material selection, originally was not evident for the TPEs. Compared with rubber, they ranged far behind in the isolated comparison of materials. The reservations, which are still applicable from case to case, related to the heat resistance under load, the deformation behaviour under pressure and the resistance to fuels and oils. Design engineers and material developers have since approached each other, have system optimized the materials and geometric dimensions and have thus made enormous progress.

Sometimes, the spreading of a new technology is also retarded by non-technical aspects. For example, samples of hydrogenated TPEs were not brought to Europe until ten years after production had been taken up in the U.S.A. There also are certain psychological obstacles which retard the incorporation of imported technology into local production, e.g. with regard to the investment in suitable machinery by hitherto preferred suppliers. Finally, the service provided by associations, e.g. obligatory designations, is an indication of the lacking advantage at home. Compared with rubber, recurrent reference is made to the price of the material which is higher for TPE types. However, this does not make itself felt in the system components with their multitude of functions. Besides a production advantage is also obtained in almost all cases.

On the road toward a rapid adjustment even of rubber materials to the demand for recycling with the aid of new TPE generations, the lengthy and capital-intensive sequences of development and introduction on the market are likely to be a serious obstacle. The solution of the problem will have to be sought at the beginning of the value added concept, i.e. when designing the raw material.

8.2 TPEs in the automobile of today

Current tendencies in the development of passenger cars refer to
- comfort,
- safety and reliability in service,
- weight reduction,
- ecological compatibility,
- design freedom and
- cost minimizing.

Considerable contributions to these development objectives are already made today by products made of
- thermoplastic polyurethanes (TPE-U),
- polyether ester elastomers (TPE-E),
- EPDM crosslinked polypropylene (TPE-V),
- polyether block amide (TPE-A) and
- styrene-ethylene/butylene block copolymers (TPE-S).

TPE-U$s have resulted from the PU thermosets. Applications comprise cable plugs, tierod ends, spring stops, spring leg covers as well as protection strip and side protection parts, e.g. on the actual Mercedes cars, here in a slightly fibre-reinforced version.

TPE-E$s are used for
- articulated shaft bellows on the wheel sides (example: made of Hytrel from DuPont, Fig. 2),
- air intake tubing (in Audi 80), cost and weight reduction at large service temperature intervals is indicated here as an advantage over chloroprene and/or epichlorohydrine rubber,
- the ring holding element with damping function in the design of the four-component bumper on the actual Mercedes cars.

TPE-V$s as EPDM crosslinked blends are nowadays represented with good quantities and growth rates. Air intake systems and blow-moulded steering sleeves have become typical applications, as have small parts such as ducting sleeves or shelf mats. The use of TPE-V in the roof drip moulding with sealing function on the Seat Toled (see title photo of this article) and Ibiza as of 1993 deserves special attention. Although initially PVC had been the only choice, this EPDM-near application might be suggestive of also including EPDM rubber in the observation of a comparative sealing function.

TPE-A is presently mainly used for small parts in the constructions and electrical systems of cars, in a smaller quantity than the systems above.

The TPE-S$s now also benefit from a remarkable uptrend, this applying to the SEBS based compounds, mostly as two-component systems in combination with polypropylene. Examples are the cowl panel sealing lip at the windscreen, the covering for water coolers, air collectors and anti-slip mats in the instrument area, hand-brake lever sleeves and headlamp seals.

About 2 kg TPE are used in recent car models. This compares with 8 to 16 kg EPDM rubber, which content might even have potential growth rates under specific aspects. Although EPDM rubber has already been replaced with TPEs in small parts, extensive investigations prove that EPDM rubber cannot be replaced in sealing systems. However, these studies do indicate the TPE systems which presently come closest to the required profile. The institutions responsible for specification and release too do not see any reason for questioning the use of EPDM rubber for sealing systems. The low hardness variants continues to be the crucial point of the application of TPEs.

8.3 Tyres

With regard to product responsability and appearance, the car tyre is somewhat outside the automotive industry. Commercial TPEs had not been intended for use in tyres. Nevertheless considerations about such use are quite necessary, although particularly difficult because of
- large quantities, one-sided selection and use of the material,
- short cycles of use,
- the particular safety requirements.

Lately a re-orientation seems to be undertaken. As early as 1988 DuPont presented a tyre safety system in which a TPE-E based supporting ring on the rim retains the service-ability even after a tyre failure. Practical applications on safety cars and in the military sector have been made.

In the meantime one tyre manufacturer has announced this principle for use on the standard passenger car. In the event of a failure, the wide reinforcing ring within the tyre permits driving on for another 300 km at a speed of 80 km/h. The ring does not in any way interfere with dismantling or rim reuse, results in an altogether lower weight than conventional spare tyres and makes them superfluous.

8.4 Current challenges for TPEs

The development of TPE applications is apparently directed above all against materials based on PVC, polychloroprene and epichlorohydrine as well as SBR and EPDM in isolated cases. The present share of 3% to 5% TPEs in the total weight of elastomers in the automobile can be expected to increase to 7% to 11% until the end of this decade - more likely complementing the range of engineering materials than being at the expense of rubber. The dispensing with the spare tyre will yield another 12%. An expansion of the market for TPEs will be possible if more flexible grades as well as grades with higher thermal stability will be offered, which in fact are now materializing.

Emphasis should here be laid on the example of the styrene block copolymers where the demand for more resistant types has already been manifested. To encourage discussion, the following could apply:

The anionic polymerization as one of the main routes to synthesize rubber and thermoplastic elastomers offers the key to tailored polymer and blend systems. In addition to the proven principle of physical network formation, this route also offers the selective grafting or the incorporation of functional building blocks and thus the continual further development towards systems with increased interaction (secondary valency crosslinking) and thus towards a broader use profile. Ionomers according to Stadler as a concept variant have shown interesting properties in the model experiment. Synthesis routes on anionic polydienes might continue to be successful because besides the molecular weight, sites of crosslinking and/or interaction also allows precise specification.

In blending processes for polymers, the addition of flexible fibres might also prove to be helpful. Small proportions of Aramid fibres in TPEs yield and thermal stability under load yet also rapidly lead to an increase in stiffness.

To obtain both better service properties and better reuse, simplification and a higher polymer content would be desirable for normal blending methods. According to this principle abrasion-resistant and non-fogging floor mats with a very good recycling potential, for example, can be made from styrene-butadiene block copolymers.

8.5 TPEs as a model case of the recycling economy

The regulation for the avoidance, reduction or recovery of waste from the disposal of automobiles has been widely accepted by now in the automotive industry. What is even more, the recycling technology has developed to be a competition parameter. Accordingly interesting is the observation of the changing choice of engineering materials.

Rubber as a material shows the familiar recycling problems. Tyre retreading and thermal utilization in cement production only matter to a certain extent since large proportions of the rubber still go to the dump (Table 8.1). In the case of tyres, these account for far more than 200,000 t/a which at roughly DM 400 per tonne involve considerable costs. In addition, there is an equally large proportion of technical rubber goods from the light shredder fraction. The further development should be
aimed at a multiple reuse of the elastomers utilized in road traffic.

For rubber the route of energy recycling will predominate on the medium term, possibly with antimission requirements. Research attempts are directed above all to the pyrolytic production of secondary raw materials and degradative extrusion. A process for hydrolytic degradation has been announced.

In the meantime, however, the goals have been set at a longer range. In addition to a short recycling loop with high value retention, maximum saving of the scarce landfill space as well as avoidance of hazardous waste must be the overriding objective of recycling. According to a future observation cycle as shown in Fig. 8.1, it will be undesirable for car manufacturers to let the car and its components get out of their reach during the periods of service and manufacture and after disposal.

Table 8.1 Recycling and/or disposal of elastomers (percentages)

<table>
<thead>
<tr>
<th>Process</th>
<th>Current</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tyres (65%)</td>
<td>tyres (35%)</td>
</tr>
<tr>
<td></td>
<td>technical goods (35%)</td>
<td>technical goods</td>
</tr>
<tr>
<td>Component recycling</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Recycling by repair</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Material recycling</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Energy recycling</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Incineration</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dumping of refuse</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>Dumping of hazardous materials</td>
<td>-</td>
<td>5</td>
</tr>
</tbody>
</table>

In the meantime, however, the goals have been set at a longer range. In addition to a short recycling loop with high value retention, maximum saving of the scarce landfill space as well as avoidance of hazardous waste must be the overriding objective of recycling. According to a future observation cycle as shown in Fig. 8.1, it will be undesirable for car manufacturers to let the car and its components get out of their reach during the periods of service and manufacture and after disposal.

Fig. 8.1 The product observation cycle as a basis for a controlled utilization of the material
8.6 Closing the circle

Almost all TPEs are suitable for materials recycling. With TPE-U importance should be attached to the absence of moisture. The fibre reinforced types are relatively unsusceptible to recycling. Besides the technology of upgrading PUR-RRIM systems is available. For the TPE-Es a semichemical process for the alcoholysis and recycling of the elastomer content (DuPont) has been developed in addition to the setup for materials recycling.

Although no practical results are available for SEBS and PP/EPDM-V type blends, the polymer structure, simulated production runs and long-term applications outside the automotive sector suggest that the property levels are retained over prolonged periods of time (up to 50 years). Besides these mechanical (shear) and thermal loads, realistic conditions of car service, such as ageing and fuel and oil contact, were simulated for TPE-V (crosslinked). Here too an encouraging forecast results for use in series production and subsequent applications.

Car-specific property retention can be a criterion for the short brand-oriented recycling loop in car manufacturer. Thus, in future, Oper AG intend to recycle the materials to their own components, also in consideration of related material dependencies. PP/EPDM-V type TPEs can thus be blended with PP or PP/EPDM unless recycled to systems of the same kind. Similarly used SEBS type TPEs can also ideally be incorporated into PP.

At any rate the ecologic-economic balance of the reuse should be considered. The ultimate decision will be governed by the specification of the recycled material, the cost of reclaiming and the prices for the new goods. An excessive expenditure in reclaiming the TPEs is not to be expected as a negative factor. The fact that TPEs find a wide range of uses other than automotive has a positive effect. Only if there were a broad application range in car manufacturer, e.g. for sealing profiles or possibly for tyres, should recycling to the same product range be sought.

8.7 Analysis as a direction sign to application

The collection of pure materials and the determination of the material present no problems in the automotive sector. Unknown components can practically be determined via the basic information by manufacturers and suppliers or by component information directly on the vehicle. The routine information should rather refer to the quality retention. On account of economical-technical parameters, the decision on the suitability of a recycled material can also be taken at the car manufacturer’s in cooperation with the supplier rather than left to a technically uncorrelatable user acceptance.

With a view to the cost-efficiency relation, the rising dumping costs will be an essential influencing factor for recycling. The question about the number of utilization cycles appears less important. Since, owing to innovation, the materials will already have been displaced into alternative applications before the end of a useful period of perhaps fifty years, the TPEs should be given fairly equal evaluation.

8.8. The market for recycled materials

Because of their price level, TPEs can be expected to become equally established as recycled materials on a lower-priced secondary market. The following factors would be important for cultivating a market for recycled materials:
- Low-cost availability even of small parts without overproportional allocation of overheads by the reclaiming shop
- Avoidance of an (undue) environmental protection surcharge in the reclaiming industry
- The goodwill of the former owners not to prevent free utilization of used material by one-sided quality interpretation or market demands.
The costs for dumping the shredder light fraction account for about DM 0.10 to 0.90 per kg, and those for rubber disposal in the cement industry, account for DM 0.10 per kg. With general-purpose plastics, the current prices for the recycled material approximately are at the level of virgin material. For the TPEs it is quite possible to decouple the price for virgin material from the one for recycled material. Although the parts are small and the dismantling expenditure accordingly high, the value retention to be expected is high.

8.9 Conclusion

The future use of TPEs will essentially depend on
- the further and new development of suitable raw materials with improved thermal stability, deformation behaviour and fuel and oil resistance,
- with the possibility of recovering the utilization potential at high value retention with a wide variety of applications and combinations in car manufacture as well as with potential uses on other markets
- Ultimately it is also necessary to increase support by industrial policy within Europe.

An influence will also be exerted by the progress made in rubber research. Some work is being done here on both the subject of recycling and the risk of nitrosamine formation.

A very successful future is forecast for the TPEs as an important component of the recycling economy in the automotive industry, not only on account of their wide application range but also and above all the high cost savings in comparison with other systems which might have to be observed after dumping or only be subject to an undesired decay of their useful value.
Chapter 9
Design for Recyclability of Automotive Interiors

9.1 Polypropylene in automobiles

9.1.1 The new materials

New developments in polyolefin-based materials have created a family of polypropylene products with a wide range of physical properties, including the ability to be easily recycled. When utilized by automotive and production designers as part of a “design for disassembly” strategy, these compatible materials will yield large subassemblies that can be reclaimed with a minimum of handling.

The intense worldwide competition which has developed within the automotive industry has been the main factor behind the exceptional growth in production technology seen during the recent years. Plastics have played a fundamental role thanks to their special capacity for interpreting the design/function synthesis. Although many different polymers are represented in an automobile today, the industry is tending more and more to favor polypropylene grades due to the large properties range available. Their growth rate shows the typical potential of “young” products, thanks to the latest breakthrough in production technology and product development. Polypropylenes have become standards of reference, where aesthetic quality, structural properties, easy processing and recyclability must blend harmoniously into the requirements of every individual item.

Fig. 9.1 shows the trend forecast for polypropylenes in the various parts of the car: from 1990 to 1995, a growth has been from about 22.4 kg/car to around 38.0 kg. Although there is increasing in-

![Fig. 9.1 Polyolefin-Based Advanced Materials Use Per Vehicle](image-url)
terest in using these materials for bodywork elements, the largest contribution to this growth, > 9.1 kg, will be from car interior components as a result of large-scale replacement of more traditional materials.

During the last decade, we have witnessed an extraordinary development in polyolefin-based materials. Thanks to important breakthroughs in production processes, finished items are satisfying diverse market requirements by offering a broad spectrum of properties. These range from the typical features of technopolymers to those of elastomeric products. All this has opened up many possibilities for the development of components able to achieve clearly differentiated performance balances while using cost-effective products within the same polymer family.

Moreover, composite structures can be obtained within the same part, by using materials with very different properties, such as:
- glass reinforced grades that offer excellent processing, low warpage and very high rigidity, used for the production of dashboard frames, air vents and sunshields
- “aesthetic” filled grades with high impact strength
- expanded grades for foam applications
- new elastomeric materials destined to play a vital role in vehicle interiors, especially as a replacement for PVC/ABS foils (Forcucci and Tompkins, 1993).

9.1.2 Processing technologies

In most cases, wide use is made of well-established processing technologies in order to minimize modifications and investments in existing production plants.

**Lamination** - During the extrusion or calendaring process polyolefinic synthetic leather can be laminated with fabrics or expanded foils. Excellent adhesion is obtained without special surface treatments. These semi-finished products can then be thermoformed and combined with supporting structures by means of adhesives.

**In-Mold Lamination** - This is a technology based on injection molding which has been widely used with excellent results. More recently there has been a growing interest in low-pressure technologies.

**Blow Molding** - Interest here is growing and a considerable amount of experimentation has been carried out in the production of instrument panels and other large components.

**In-Mold Graining** - This technology is especially suitable for the production of items of medium to low complexity. In this case, the smooth foil, combined with expanded polypropylene, is thermoformed and embossed directly in the mold and then glued on the supporting frame.

9.1.3 Concepts for car interiors

The performance properties of polypropylene have multiplied so quickly during the past ten years that it is now realistic to anticipate a trend toward employing a single material to manufacture very complex structures such as automobile interiors. The objective is to develop cooperative effort with our customers and produce interior components of olefin-based materials exclusively. The main advantages are:
- easier disassembly through design planning
- better recycling quality because of materials compatibility
- elimination of odor and “fogging” due to plasticizer outgassing
- good resistance to chemicals
- good resistance to aging
- weight reduction

In each concept, the designs incorporate readily identifiable hard point connections between the PP components and the metal automobile subframe. This will allow personnel in reclamation centers to strip these parts out of junked cars quickly, in large pieces that can be completely ground up and
reclaimed/recycled.

**Instrument Panel** - The sketches below illustrate how structurally sound parts can be produced using new technologies to yield components completely based on polypropylene materials. Instrument panel elements can be textured and integrally colored during manufacturing. In addition, intermediate levels of finishing can be achieved by means of partial coating or soft painting.

**Doorpanels** - This component tends to evolve from a simple decorative element to a more functional one and makes a significant contribution to the quality of the vehicle. Polypropylene materials allow the production of “integral” structures of aesthetic and functional elements produced within the same family of materials that allow the production of “integral” structures of aesthetic and functional elements produced within the same family of materials. The frame and arm rest are injection molded of glass filled PP. Trim parts are produced in lightweight panels or thermoformed sheets which are laminated with fabrics, calendered film materials and/or carpeting. PP air ducts are also included.

**Console** - The design shows an injection molded, filled grade of PP with in-the-mold TPO “leather” or fabric panels. The storage door-arm rest is made of foam and textured film, laminated and vacuum formed over the base molding. A blow molded air duct is part of the assembly.

**Pillar Trim & Rear Shelf** - Blow molding has been used for the pillar trim to provide the double functions of air ducting and aesthetic trimming. Finishing is provided during the molding process with the application of fabric or textured film. The support structure may be filled or unfilled types, depending on the mechanical properties required. For the rear shelf, the design presented is a vacuum formed laminate of extruded PP and woven fabric.

**Table 9.1 Specifications: Characteristics**

<table>
<thead>
<tr>
<th></th>
<th>Traditional: Septum</th>
<th>New: Modified TPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight per Unit Area</td>
<td>4400 g/m</td>
<td>4800 g/m</td>
</tr>
<tr>
<td>Thickness</td>
<td>2.1 mm</td>
<td>2 mm</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>5 kg/cm</td>
<td>15 kg/cm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Traditional: Sep + Porous</th>
<th>New: TPO + PP Felt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight per Unit Area</td>
<td>900 g/m</td>
<td>300 g/m</td>
</tr>
<tr>
<td>Thickness</td>
<td>14 mm</td>
<td>4 mm</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>1 kg/cm</td>
<td>1 kg/cm</td>
</tr>
<tr>
<td>Rotting</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Odor</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Compression Set</td>
<td>15%</td>
<td>1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Traditional: Porous</th>
<th>New: PP Felt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning Rate</td>
<td>75 mm/min</td>
<td>Nonflammable</td>
</tr>
<tr>
<td>Sound Insulating</td>
<td>27 dB</td>
<td>27.4 dB</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>25%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

The comparison of the new solution and the conventional flooring system is shown in Table 9.1.

**Floor Covering** - This interactive system of polypropylene components is of special importance in establishing the comfort level of the car interior. The layers of filled PP for sound deadening, non-woven PP felt and long wearing PP carpeting create a cost effective, versatile floor covering that is compatible and readily reground. A trimming scrap from inplant manufacturing can be directly recycled to produce the rigid base structure.

**Head Liner** - This last important application is perhaps the most critical of all those mentioned because of the great opportunity for labor reduction and materials compatibility. Still in the early stages of development, the sketch shows an approach which answers the main requirements for this
component-light weight and rigidity at high operating temperatures. The exterior surfaces of the lin-
er can be either embossed foils or fabric, in any combination.

9.2 Recyclable Instrument Panel Systems

9.2.1 Automotive Instrument Panels

The instrument panel of automobiles is comprised of three major constituents: the structural re-
tainer or carrier, a foam which varies in durometer from car line to car line, and the skin, which is the
material surface visible to the customer. Very few of these component systems are manufactured from
the same family of materials today.

The present construction for many of the I/P’s in the automotive industry is that of an S/MA re-
tainer, PUR foam, and a PVC/ABS skin. The skin is applied in either a vacuum formed process, or
foamed behind a cast skin.

The vacuum formed process is the lowest cost skin manufacture process and allows for good di-
mensional control of the product. Changes involving the surface can be implemented at a low cost.
Grain wash out during the forming operation is problematic with this material, as well as a hard tac-
tile feel and decreased physical properties with heat aging.

The cast skin process typically provides styling latitude and choice of surface finishes that are not
available with vacuum formed materials. However, mold changes are costly and the weatherability of
this PVC falls below the other I/P skin materials.

Recycling I/P’s of the current construction becomes more labor intensive and costly. Instead of re-
cycling the entire system (retainer, foam and skin), as can be done with either the olefin or urethane
systems, several steps must be taken. First, the vinyl must be stripped and separated from the foam.
The vinyl can then be used in other componentry. The foam is chemically stripped from the retainer
and packaged off for sale to various companies for reuse. The S/MA retainer material can than be re-
cycled for reuse into another retainer. Davison Textron currently uses this technique on I/P’s taken
back from Ford of Europe after the vehicle has served its useful life.

Polyolefin system - The triolefin system described below details the developments within the
polyolefin industry that has brought the possibility of utilizing an all polyolefin instrument panel clos-
er to production.

Retainers - A possible olefin system could begin with the structural portion of the lower I/P, man-
ufactured from a glass fiber reinforced stampable sheet. A typical glass loading is on the order of
30%. The glass fibers are introduced into the polyolefin based slurry rather than impregnating a glass
mat with the polyolefin resin.

The fibers are therefore more uniformly distributed throughout the sheet. Parts compression mold-
ed or injection molded from these sheets can provide greater structural integrity for integrally mold-
ed duct work, PSIR mountings and pedal attachments.

Alternatively, the structural duct may also have the capability to be blow molded, however, there
may be concerns with dimensional stability.

The upper portion of the I/P retainer, or carrier, may be manufactured from either glass fiber re-
infroed polypropylene as an injection molded part, or as a blow molded part manufactured from a
lower flow (higher melt strength) material. Utilizing this technology may permit the molding of the
heater and air conditioning duct work into the retainer, leading to a reduction of parts and ease of
manufacture. The Honda Accord currently employs this type of system.

Several benefits can be realized from molding the I/P upper from polyolefin resins. The high melt
flow materials may lead to a reduction in cycle time of up to 15%. The resultant part will have an ex-
cellent balance of stiffness and strength, as well as good room and cold temperature impact resis-
tance.
Foams - Polyolefin foam technologies are not designed to replace the foam in place (FIP) urethane products currently used for instrument panels at this time. The use of cross linked polyethylene foams may compromise the recyclability of a triolefin system (Montpetit, 1993).

Polypropylene foams are available with densities ranging from 24-160 kg/m³. These foams are not crosslinked, and derive their strength from the stress hardening of the cellular walls. The foams perform well on initial impact, but performance is subpar on repeated impact due to the collapse of the cellular walls. These materials may be thermoformable up to a thickness of 3 mm.

I/P Skins - The material of choice for an I/P skin in a triolefin instrument panel is a rubber modified polypropylene, or TPO. These materials can be processed at PVC line speeds, but at a slightly higher temperature. The skin can be embossed or printed (Flexography and Rotogravure).

The TPO skin, available in thicknesses of 0.23 and 0.46 mm, is laminated to the polypropylene foam through a calendering operation, at which time the desired grain is embossed onto the skin surface. The finished I/P is then manufactured in one of two ways: 1) the resultant skin and foam is thermoformed over the hard polypropylene retainer which has been treated with an adhesion promoter, or 2) the skin and foam may be placed in an injection mold, and the retainer formed behind the skin and foam laminate.

There are several benefits to TPO skins; 1) As manufactured, these materials will not fog, 2) Reactor grade materials provide better lot to lot consistency, 3) Better weatherability, chemical resistance, and UV stability when compared to PVC compounds, 4) Lower specific gravity than PVC, and 5) Improved mechanical properties over conventional PVC skins.

The triolefin system has the potential of being a totally recyclable system, but several problems must still be overcome.

1. Design flexibility: The single greatest drawback is that the process cannot yield a highly styled I/P. The skin material is too stiff to allow for conforming to styling lines without “washing out” the grain during the forming operation. The current foam systems do not allow for the design flexibility available with the FIP foams, and as a result, I/P’s manufactured from the triolefin system, are generally flat with little contour, when manufactured by a typical vacuum formed process.

2. Dimensional capability and stability of the retainer.

3. Reflective glare: Vehicles are now being designed with highly sloped windshields. As a result, the reflectivity of the sunlight off the skin causes a reflection of the I/P to be visible to the driver as he looks through the windshield. To eliminate this glare, the skin of the I/P must be painted to obtain a lower gloss. For an olefin material, an adhesion promoter must first be applied to the skin prior to the top-coating operation. This extra step results in an increased component cost. Concerns also exist about “markoff” of the painted part.

Competitive Processes - Urethane Systems. The urethane system is comprised of a glass reinforced (RRIM), full density reaction injection molded retainer, with a foamed in place urethane foam, and a sprayed, or cast, urethane skin.

The FIP urethane foams provide the greatest degree of design flexibility of any of the foam systems available, at durometers that are not yet available in the desired thickness from olefinic foams. FIP systems are also more economical than the olefinic foam systems at this time.

The urethane skin provides excellent durability to solar exposure (weathering), styling latitude for surface effects with no grain washout, and a soft, pleasant, tactile feel. The broad temperature range and tear strength properties of the urethane skin material make it an excellent choice for SIR and PSIR applications. However, changes to the mold surface are costly and require time. The design of the panel is limited by the access of the spray head. This process will yield a highly styled I/P, with a large degree of design flexibility. All of these materials are thermoset urethane based products that can be recycled by various means (3'rd stream process to make new parts, compression molded with an increased polyol content, etc.). When compared to the olefin based proposals or the present combination of materials (S/MA retainer, PUR foam, PVC/ABS skin), the final cost of the urethane pro-
posal will be marginally greater. However, the weatherability of the sprayed urethane material is sec-
ond to none.

**I/P Componentry** - One of the advantages of the olefin I/P system is that I/P hard plastic trim (de-
froster grille, air vents, cross car trim plates, bracketry, hush panels, knee bolsters, etc.) can be man-
ufactured from polyolefin based materials. This enables the automotive dismantler to strip the I/P of
all metallic and electronic components, and submit the remaining hulk from the I/P for recycling as
polyolefin scrap. I/P systems based on the other detailed systems would have to be stripped of all I/P
componentry prior to recycling, a time consuming and costly operation.
Chapter 10
Recycling batteries

10.1 General features

10.1.1 Introduction

Batteries literally empower many kinds of portable electric and electronic devices, such as telephones, computers, radios, compact disks, tape recorders, cordless tools, and even electric cars. But at end-of-life they can come back to haunt us.

Batteries in general may be classified as either primary – lasting for a single life cycle—or secondary, in which case they are rechargeable and may last for thousands of cycles. From an environmental viewpoint, a secondary battery is preferable to the primary kind; in mass of materials alone, a single rechargeable cell may be functionally equivalent to dozens of primary cells. Even so, secondary batteries lose out to primary batteries for consumer cells, where the life-cycle cost is not the customer’s prime concern.

Worldwide, hundreds of millions of large batteries and billions of small ones, containing tons of toxic and hazardous metals, are produced and used up each year. Until recently, most of them were simply discarded. Even today, only automotive-sized lead-acid and industrial nickel-cadmium types are systematically collected for the sake of recycling their materials.

Consumers’ batteries are much smaller and have for the most part ended up with other discarded products in municipal solid waste. When the waste went to a landfill, water leached the nickel, cadmium, and mercury from the broken batteries, and high concentrations of the metals showed up in the leachates collected from the landfill base. When the waste went to incinerators, the batteries contributed high levels of metal fumes to the stack emissions and ash, so that the cost of environmental control went up, too. Used batteries accounted for nearly 1.5 million metric tons of municipal solid waste in 1994 (From here on, the term ton will stand for metric ton, or 0.907 of a short ton.). This quantity was less than 1 percent of the total municipal solid waste generated, yet accounted for nearly two-thirds of the lead, 90 percent of the mercury, and over half of the cadmium found in that waste.

In the United States, regulations in most states mandate removal of lead-acid batteries from municipal solid-waste incinerators and landfills, requiring the items to be recycled or else disposed of in landfills intended for hazardous waste. In many other countries, regulations require either the return and recycling, or the safe disposal of used batteries.

The concern stems from the toxic nature of many battery materials. Toxicity limits are set for workers handling the materials, and drinking water and ambient air standards are set for everyone. For example, a worker’s maximum allowable inhalation of the substances is measured in milligrams per cubic meter during an 8-hour period. For nickel, it is 1 mg/m$^3$; for lead, it is 0.15 mg/m$^3$, and for cadmium, 0.005 mg/m$^3$.

As guidelines for water supply facilities, countries set maximum contaminant levels (MCLs) beyond which water is judged unsafe to drink. The U.S. NICL for lead is 0.05 milligram per liter, while for cadmium it is 0.01 mg/L; no nickel MCL has been set yet.

Lead, cadmium, mercury, nickel, and their compounds are included in the U.S. Environment Protection Agency’s list of toxic release inventory (TRI) chemicals, and highest priority was assigned to the reduction of their emissions under the agency’s 33/50 voluntary toxics reduction program (its goal being a one-third reduction of such pollutants by 1992 and their halving by 1995). Lead is regulated
as one of six ambient air pollutants under the U.S. Clean Air Act. It is the reason why 10 air quality regions in the United States fail to comply with the regulation that the quarterly lead average be less than 1.3 micrograms per cubic meter of air (Mc Michael and Henderson, 1998).

Disposing of millions of tons of toxic materials is an enormous problem for solid waste management and presents varied risks to the environment. As the demand for batteries climbs throughout the world, the damage and riskiness could climb, too. So it is just as well that the current end-of-life treatment of many batteries is being changed by greater incentives and requirements for recycling. Toxic metals and metal compounds, corrosive electrolytes and mixed residues of these materials and plastics pose challenges for managing the afterlife of this consumer product.

Worse still, from the standpoint of sustainable economic development, batteries have their downside. On the one hand, to promote environmental sustainability, it is desirable to limit toxic emissions and ensure re-use of resources such as battery metals-goals that encourage interest in battery recycling. On the other, the cost of collecting and processing, discarded batteries is generally more than the revenue to be obtained from the metals recovered, so that dead batteries lack a positive value, unlike automobiles and many electronic components, including computers. In effect, they will rarely get recycled without regulatory requirements or special financing, arrangements such as deposit/refund programs. Otherwise, it can be difficult to meet aggressive goals for voluntary recycling programs.

Effective recycling involves changes at all earlier stages of battery life as well, starting with production. Manufacturers should attempt to use recycled materials themselves, label batteries clearly for easier sorting, and ensure that batteries can be effectively recycled. Consumers need to take part in recycling programs by separating batteries from other wastes – doing so after their disposal in general municipal solid wastes is quite expensive per ton of battery material recovered. Retailers and shippers are needed to collect and return post-consumer batteries to recyclers. Finally, recycling plants and processes are needed for each of the various battery types and materials.

10.1.2 Materials management

Requirements for battery recycling vary from country to country, with a clear trend toward stricter controls of those requirements as well as disposal options. Still more sweeping regulations are under active consideration. For example, the European Union has drafted a directive that would require recycling of at least 75 percent of all used consumer batteries and 95 percent of all industrial and automotive batteries.

Reported recycling rates can be easily misinterpreted. The fraction of battery material actually recovered is the product of three factors: the fraction of batteries sold that is returned, the fraction of material recoverable from each one, and the fraction of the recoverable material actually recovered. Take the retrieval of lead from lead-acid batteries: here, the return rate is roughly 95 percent, the recoverable lead in the battery mass is roughly 60 percent, and the efficiency of a secondary smelter is roughly 95 percent. All in all, the material recycle fraction of the battery mass would then be 54 percent.

It is also common for recycling rates to be quoted with little attention to how much of an item is actually being recycled. Whole batteries are rarely recycled. As metal electrodes are the easiest element to retrieve, lead electrodes are routinely recycled, whereas lead in spent electrolyte or sorbed in used battery cases is typically not recovered.

Dead batteries, after all, are not what they were to begin with. Their use changes them physically and chemically. Electrodes may corrode and deform so that an electrical circuit fails. Chemical reactions may not be wholly reversible upon recharging. Consequently, battery components may not be reusable directly, but need processing before being recycled, whether into new batteries or for other uses.

Battery recycling divides into several distinct steps: collection of used batteries (the converse of distribution), sorting, recovery of recycled material, its purification, and disposal of nonrecycled ma-
terial. By and large, recycling of lead-acid batteries is pretty common; commercial processes for nickel-cadmium and nickel-metal hydride batteries are in place; and experimental or bench-scale process demonstrations exist for other battery types but they undergo little actual recycling.

10.1.3 Battery design issues

A systems approach to battery recycling based on a life cycle analysis begins at the product design stage with some critical questions. Specific design issues would include:

- Does the product that runs on batteries allow for or encourage the use of the rechargeable type?
- Are labels included that encourage recycling and proper disposal?
- Are labels for material content attached, so that it is easy to sort used batteries?
- Are products designed so that batteries can be removed easily?
- Are recycling processes available for exotic battery materials such as lithium?

More fundamentally, there is sporadic interest in ridding batteries entirely of particular toxic materials such as mercury. Even without wing so far as to eliminate them, systems to ensure that these harmful substances are re-used, rather than being unleashed on the environment, are needed.

10.1.4 Systematic collection

The collection stage of a recycling system consists of separating a battery from the product it powers, storing it, and transporting it to a processing or disposal facility. Many of the most costly decisions about recycling arise at this stage, like whether to establish a reverse logistics system that would recover post-consumer batteries.

A collection system for used batteries is the first step. In Europe and Japan, all battery types are collected by retailers or recycling stations, but in the United States things are more complicated. Still, everywhere batteries are sorted by type and either recycled or disposed of in bulk. Practices for different battery types vary from country to country.

Large batteries, weighing tens of kilograms or more, present less of a problem than smaller sizes. Historically, large industrial cells were sent to a metal recovery facility if that procedure cost less than disposal to a hazardous-waste landfill. Conversely, U.S. Federal waste regulations exempt small consumer cells if the quantity of used batteries is less than the rate required to exceed the small generator limit (100 kilograms per month) or if the used cells are mixed with other municipal waste.

The lead-acid batteries used in vehicles must by law in the United States and many other countries be collected for recycling. Thirty-two of the United States have laws banning the disposal of these batteries in landfills or incinerators. Retailers are required to take a used starting, lighting, and ignition (SLI), or automotive, battery in exchange for a new one or to charge a penalty until the used battery is dropped off. The sealed lead-acid cells used in electronic devices are not covered by these regulations, but they form only a small fraction of all lead-acid batteries.

The recycling rate of nickel-cadmium batteries is quite low but rising. Common uses for these types are in portable devices such as computers, telephones, and cordless tools. Larger U.S. retail chains, like Radio Shack, Kmart, and Wal-Mart, maintain drop-off cases in their stores as a service to customers who may bring in used batteries. This system calls for vigilance to keep unwanted battery types from being mixed in with the NiCd discards. Alternatively, used NiCd cells may be sent to recyclers through commercial parcel services.

The 1996 U.S. Rechargeable Battery and Mercury Removal Act mandated labeling of NiCd batteries and called for the establishment of a collection system, including the processing of batteries for the safe recovery or disposal of their materials. The Rechargeable Battery Recycling Corp., Gainesville, Fla., is an independent, nonprofit, service corporation whose mission it is to educate the public on the importance of recycling NiCd batteries. The organization works with retailers, municipalities, and counties in the United States to develop recycling programs.

It gives retailers containers in which to collect used NiCd batteries and it pays for their shipping
to a recovery firm. Its work is financed by licensing the use of its corporate seal on NiCd products. More than 155 companies, which manufacture 80 percent of the NiCd batteries sold in the United States, have signed licensing agreements. In May 1997, the organization expanded its program to Canada.

Besides its licensees, the recycling corporation collects from three other sources: retailers, communities, and business and public agencies. Shipments originating from 11 states west of the Rockies are sent to a consolidation facility in Anaheim, Calif., before being passed for recycling to International Metals Reclamation Co. (Inmetco), an Ellwood City, Pa., subsidiary of International Nickel Corp. Other locations ship directly to Inmetco. Small shipments of batteries, less than 70 kg, are shipped by United Parcel Service and larger quantities by common carriers. Reorganization estimates it recovered about 15 percent of the batteries sold in 1995; they came primarily from the commercial sector, with less than 4 percent of the total from households.

Retailers of specialty electronic devices serviced with button cells have sometimes installed drop-off containers for these batteries. The service was offered to customers when they visited the store. Button batteries are not labeled explicitly, so it is not easy to distinguish between high-value cells with large fractions by weight of mercury or silver, and low-value or valueless batteries like alkaline manganese or aluminium oxide.

As for consumer primary batteries of the carbon zinc or alkaline manganese type, they are produced in the largest numbers worldwide. U.S. Federal waste regulations classify them as nonhazardous, and the United States has no widespread systematic program for their collection and recycling. Under certain conditions, broken or damaged battery cases will cause these batteries to fail the chemical extraction tests of the Environmental Protection Agency (EPA), based in Washington, D.C., whereupon they are classified as hazardous waste. Battery manufacturers are treated differently from the general public; their spent or off-specification batteries are viewed as hazardous waste.

The collection of used batteries and their delivery to a processing facility and storage there is followed by sorting. Labeling should assist the sorter to separate incompatible materials. For example, lead batteries should be kept apart from cadmium batteries. The sorting is important because different industrial processes are used to extract material from the different types of batteries.

10.1.5 Technologies of recycling

Several processes may be used to recycle battery materials (Fig. 10.1). The metals are recovered by pyrometallurgy, which uses elevated temperatures; hydrometallurgy, which uses water extraction typically at ambient temperatures and pressures; and electrometallurgy, which uses electricity.

Most of the methods of recovering lead (Fig. 10.2) use the first of these techniques, employing primary smelting operations mainly for ore or secondary smelting operations mainly for scrap. Nickel and cadmium recovery is also mainly done with pyrometallurgical processes. Facilities designed to handle all types of batteries are likely to include a mix of all kinds of metallurgy in addition to techniques of size reduction and physical separation.

Lead-acid batteries have the most advanced system for end-of-life management worldwide. In the United States, the program for the industry is managed and monitored by the Battery Council International, Chicago. The average recycling rate for the lead in automotive batteries was calculated as 95 percent by the council for the years 1990-95. As roughly 60 percent of all U.S. lead production is used by batteries, their return rate of 95 percent is an important material flow. Other components of starting, lighting, and ignition (SLI) batteries are usually not recycled.

A typical process for lead-acid battery recycling would start with used batteries stored at a secondary smelter as whole or drained units. Any whole batteries are drained of electrolyte and sludge, all the cases are broken up, and materials other than lead separated from the mainly lead and lead oxide electrodes. Heating and thermal processing produces a refined lead that can be reused. Materials other than lead may be handled as hazardous waste or possibly converted into a product for a sec-
ondary market—for instance, a major auto manufacturer processes the polypropylene cases of SLI batteries into automobile mud-flaps. The expectation is that retrieval of materials other than lead will increase in the future.

Smelting operations, of course, have their own environmental costs. Without proper waste controls, their air and water emissions can exceed Federal and state standards. Outside the United States, Italy affords another approach to lead-acid battery recycling. In 1988, Italian law established a consortium, Cobat, to organize an efficient collection network for spent lead-acid batteries and lead scrap and their recycling throughout Italy.

Cobat’s domain includes: organization of the collection and storage of these materials; their delivery to national or foreign industries for recycling; ensuring that, if battery materials cannot be economically recycled, the waste is “eliminated in compliance with strict environmental standards”; and promotion of research for improved recycling and disposal of lead.

Italy’s annual demand for battery lead is about 240 thousand metric tons, of which 40 thousand are imported and 200 thousand are produced domestically, including 80 thousand metric tons from recycled lead. The consortium’s five recycling plants serve the whole country. Cobat estimates that the collection system misses about 6 percent of all of the discarded lead batteries in the do-it-yourself small operators dealing with marine, personal auto, and agricultural sectors.

Batteries are not recycled in their entirety but in terms of their components—in the main, the electrodes, the electrolyte, and the electrode separators and case.

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**Fig. 10.1 Different processes to recycle battery materials**

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<table>
<thead>
<tr>
<th>Battery type</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid</td>
</tr>
<tr>
<td>Lead acid</td>
<td>Plastic or Steel</td>
</tr>
<tr>
<td>Nickel cadmium</td>
<td>Plastic</td>
</tr>
<tr>
<td>Nickel metal hydride</td>
<td>Steel</td>
</tr>
<tr>
<td>Alkaline</td>
<td>Steel</td>
</tr>
</tbody>
</table>

*Recovery for use as a process reagent possible* Source: Carnegie Mellon University
Transportation
The network for distributing new batteries also transports spent batteries from the point of exchange to recycling plants.

Spent batteries
At the recycling facility, spent batteries are broken up into their component parts.

**Plastic**
Old battery cases and lids yield plastic pellets.

**Lead**
Old battery grids and lead oxide yield lead ingots.

**Sodium sulfate**
Old battery acid is separated into sodium sulfate crystals, sold for use in manufacturing, textiles, glass, detergent.

**New cover and cases**
The plastic pellets are turned into new battery cases and lids.

**New grids and lead oxide**
The recycled lead is turned into new battery grids; recovered lead oxide is also used in new battery manufacturing.

**New cases and lids**

**New grids**

**Lead oxide**

**New battery**
New batteries are recyclable and composed of already recycled materials.

Fig. 10.2 Steps to recycle lead batteries
Recycling is different for each component. Metal electrodes are recycled most. Metal cases are recycled more than plastic cases. Electrolytes may be reused as reagents, but in some circumstances may be recycled for other uses.

Lead is the battery material most recycled; cadmium is the focus of recent efforts and ranks second. Records for other components are not maintained systematically.

A modern facility for recycling spent automotive lead-acid batteries is a large operation. This new plant in Georgia can handle almost 13 percent of those ousted by the U.S. replacement market – 70 million out of a total annual U.S. production of some 80 million.

From 9 million used batteries, this facility expects to recycle 90 million kilograms of lead and 9 million kilograms of plastic.

The lead from lead-acid batteries and the cadmium from nickel-cadmium batteries are recycled in a closed loop – they are used to manufacture more batteries. But recycled nickel disappears into another industry. Electrolytes, too, are rarely recycled into battery electrolytes. A drawback is that environmentally harmful emissions are generated from the pyrometallurgical processes (Fig. 10.3).

10.1.6 Costs of detoxification

Concern for the environment exacts a price. Neither recycling nor disposal comes cheap. Primary batteries have been made more benign by U.S. and European regulatory change in their chemical composition: mercury may no longer be added to the anode, and limits on the acceptable level of mer-

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**Fig. 10.3 Used batteries closed loop**
cury are being progressively lowered—at present to less than 1-5 ppm by state and Federal laws. Granted, the chemicals that replace mercury lead to less efficiency and higher costs, but mercury-less batteries are accounted nonhazardous waste in the United States.

Secondary batteries, too, are dogged by higher life-cycle costs due to requirements for collection and recycling. When lead-acid automotive batteries were declared a hazardous waste by EPA in 1995, the regulation did not call for a change in battery composition, but required retailers to take a worn-out battery in exchange for each replacement they sold or else collect a penalty charge or receive evidence of proper disposal of the spent battery. Used automotive batteries are purchased by scrap metal dealers in the United States for 3-5 cents per pound. At these prices, a typical auto battery weighing about 18 kg can bring $2 at its demise.

The Portable Rechargeable Battery Association, representing the major secondary battery manufacturers, and the Rechargeable Battery Recycling Corp. changed the end-of-life options for owners of used NiCd batteries. The corporation’s system holds manufacturers responsible for the main costs of collection and processing—namely about 57 cents per kilogram for the right to use the corporation’s recycling seal.

Choosing to pay for the seal is voluntary, but all NiCd with or without the seal must be labeled and recycled or disposed of as hazardous waste. The recycling corporation estimates its costs for collecting and recycling NiCd batteries in 1996 at $5.5 million, or about 1 percent of NiCd sales. At a recycling level of more than 2.25 million kilograms in 1996, this is about $2.220/kg, similar to the costs of disposing of hazardous waste. Since most NiCd batteries are contained within products, the added costs may escape the consumer’s notice.

Italy, as before, does it differently. To finance its activities in collecting and processing used lead-acid batteries in that country, Cobat has two sources of revenue. One is levies from battery sales: the purchase price of the battery includes the levy, which is paid directly to the consortium by producers and importers. The other is the proceeds from the sale of scrap batteries to recycling plants, subject to variations of the price of lead on the London Metal Exchange, and to the varying cost of processing and disposal of toxic wastes.

Average results of the Italian scrap lead battery system for 1992-95 were: per kilogram, costs of $0.12 and proceeds from sales of $0.05 to yield a net operating deficit of $0.07/kg. Collection costs are on average $0.10/kg, or about 87 percent of the operating costs, and represent the major financial issue for the whole operation.

France did something similar. In 1989, Savam developed a charging formula, which it based on the world price of nickel and cadmium, and estimated from expected sales revenues that battery materials returned in 1989 would be charged $3.20/kg.

Two years later, Switzerland’s Recymet reported processing fees of about $6.60/kg exclusive of collection and shipping costs to Switzerland.

Proper disposal of batteries has no direct monetary reward. Landfill “tipping” fees for hazardous materials are usually five to 10 times higher than for ordinary municipal solid waste. Consumers find it cheaper and more convenient simply to throw their batteries away with other garbage (or let them commingle with other municipal solid waste), giving rise to contaminated landfill leachate or incinerator emissions, as noted earlier. Full cost-accounting of disposal streams should be a priority for corporations or organizations charged with managing battery disposal.

One sizable expense in battery disposal is the cost of reverse logistics. To the extent that batteries can be consolidated in retail stores, the costs of retrieving particular battery types is lower. In the extreme, batteries may be returned individually by parcel post.

Still, as nickel-cadmium battery recycling becomes more common, reverse logistics costs should decline to a level closer to the costs of lead-acid battery collection.
10.1.7 Prospects ahead

A 1992 study by a New York State task force defined an ideal battery as one that: has no toxic components, never needs to be discarded or is easily and economically recycled, can be safely handled, and has superior performance characteristics for the particular application. This system definition uses “ideal” in the sense that the life cycle characteristics must all be examined before it can be decided if a battery type meets this ideal or green description.

Recycling, a reality now for some battery types, is likely to become important for all batteries in the future. Consumer demands, regulatory pressures, and corporate policies are all motivating more recycling. Most of the interest centers on removing toxic materials from the waste stream, but reuse of resources, particularly the scarcer metals, also counts.

For managing the recycling of batteries, product-takeback is the emerging paradigm. In this approach, manufacturers bear the responsibility for arranging reverse logistics systems and battery recycling. The arrangement can be instituted by the manufacturer, either individually or as a consortium or a third party financed by manufacturers. The advantage is that it takes disposal decisions out of the hands of consumers who are often confused about the consequences of different end-of-life choices. In fact, product takeback responsibilities are likely to extend to other electronic products in the future, as can be seen in Germany already.

Recycling all the parts of batteries is not common. Research has shown that recycling of more of their components and materials may be technically feasible, but markets for materials other than metal are generally not available. An exception here would be the growing recycling of lead-acid battery components like cases.

Metal recycling is not invariable. Retrieval of lead from batteries is widely practiced and accepted as a regulatory requirement. A concern here is how far trace losses of lead to the environment can be prevented during collection or smelting, so that a closed-loop lead-use-and-recycle system can be sustained indefinitely. Achieving this type of system is the ambition of the emerging discipline of industrial ecology.

Recycling nickel-cadmium batteries is now emerging as a commercial enterprise, with both metals being recoverable. As with the lead-acid battery, recycling NiCd cells is typically either subsidized by manufacturers or required by regulation. Efforts aim at recovery of cadmium for the battery market and recovery of nickel for other markets.

In fact, the success of the fledgling attempts to recycle NiCd batteries may be crucial for their growth and use over the long term. Given the toxicity of cadmium, active efforts are being made to eliminate its use in other applications and to restrict disposal options. So far, the market for the metal has been fairly stable since other uses have diminished while NiCd battery production has soared. As those other uses are eliminated, cadmium could become really scarce, further spurring pursuit of effective collection and recycling processes. Indeed, without effective recycling and cadmium reuse, there may be long-term supply problems.

As for other battery types, recycling is technically feasible but has not been applied widely. Exotic battery materials are an active area of research, and some attention should be paid to developing recycling processes for these materials. And some of the newer battery types are advertised as “green” on the basis of their high power densities or lower material toxicities. Debate continues on what constitutes a green battery, but certainly lower resource requirements and good systems for recycling are critical.

Environmental concerns might also influence device design and choice of alternative battery types. For example, electronic devices should be designed to ensure that toxic battery metals can be extracted. This typically involves opportunities for removing batteries and proper labeling.

Eliminating reliance on toxic materials is also to the point. Any use of such materials involves environmental risks and sends trace emissions into land, water, and air. If pollution is to be prevented, everyone would benefit if cost-effective and efficient alternatives to the use of toxic materials such
as the cadmium and lead could be found. Batteries such as the aluminium air or lithium polymer or new technologies such as fuel cells may in the future circumvent the toxic metal problem altogether.

10.2 Closed loop recycling of lead/acid batteries

10.2.1 Collection rate of lead/acid batteries

The recycling loop for lead/acid batteries is operating very well in Western Europe. This is especially true when lead/acid batteries are compared with other recyclable products. In Western Europe, the collection rate of lead/acid batteries is well ahead of the rates for glass, paper or metallic cans (see Fig. 10.4). Furthermore, the latter materials are themselves at the forefront of recyclable products.

The average collection rate of 85% for lead/acid batteries (Fig. 10.4) is obtained as follows (Fig. 10.5). The first step is to calculate the theoretical resource of battery scrap (i.e., the amount before any battery is lost). For industrial and small batteries, it is usual to base this calculation on the average service-life of each battery type and its past consumption levels. For automotive (SLI) batteries, it is possible to escape from the uncertain value of the average service-life, by assuming that scrapped batteries equal the sales of replacement batteries plus those collected from broken vehicles (i.e., in number, but not in weight, of batteries). Finally, the process scrap from battery plants and the imports/exports of batteries must be included to obtain the theoretical resource of battery scrap (Charretton, 1993).

A comparison of the theoretical value with the quantity of battery scrap delivered at lead smelters yields the apparent recycling rate. Why apparent? This is because stock variations are very poorly documented (it is well known that they are linked to the frequent fluctuations in the lead price), and because no consideration has been given to the delay for collection and stockpiling (this delay is estimated to be the order of a year).

Despite the fact that the recycling rate is only an apparent figure (it lies between 80 and 90% of the real value), the rate should be normalized for Western Europe in order to check its evolution over several years. This is necessary at a time when the EEC Directive on battery recycling is becoming effective, and when various countries are implementing collection schemes for lead/acid batteries that are aimed at increasing recyclability.

The collection rate of industrial batteries is already very good; it is close to 100% (this should also be the case in future for batteries employed in electric vehicles). Thus, most of the improvements should focus on the collection of automotive and small batteries. These products are consumer goods

![Fig. 10.4 Estimated collection rates of various recyclable products in Western Europe](image)
and, consequently, require the active participation of the consumer to achieve a very good recyc-
leability.

10.2.2 Recycling rate of lead/acid batteries

The recycling loop of lead/acid batteries is not yet perfect. In addition to the above-mentioned col-
lection rate, the recycling rate of the battery itself can be improved (see Fig. 10.6).

The free acid of a battery is often lost before the scrapped battery arrives at the smelter (this rep-
resents about 15% of the total battery weight). The collection and transportation network is current-
ly attempting to implement the recycling of full batteries. At smelters, the free acid that is not lost is
collected and completely neutralized.

At secondary-lead smelters, batteries are crushed, and their various components separated. The
lead from grids, connections and paste (about 55% of battery weight) is smelted and refined to meet
the high-quality standards of the automotive industry, and then recycled in the battery industry itself
or in other industries.

![Diagram of recycling process](https://example.com/diagram.png)

Fig. 10.5 Apparent recycling rate of lead/acid batteries - year N.
The remaining acid and sulfate (about 20% of battery weight) are recovered in the soda slag that is produced by the smelter. Metallurgists are working towards further reducing the volume of slag that is produced.

The polypropylene from battery cases is also separated (about 5% of battery weight) and recycled in the form of polypropylene granules to make components for the automotive industry, containers for horticulture, etc. There are also various plastics that are not polypropylene (e.g., polyvinylchloride, polyethylene, acrylonitrile/butadiene/styrene). These originate from separators, envelopes or cases, and cannot be effectively separated and recycled. Such plastics are therefore dumped (about 5% of battery weight). Battery manufacturers must promote the use of materials that are easy to recycle at the end of battery life.

Finally, an active partnership between all the participants of the recycling loop is encouraged, in order to reduce breakages in the loop. This is likely to increase further the recycleability of the lead/acid battery, a product that has already set the standard in the field of product recycleability.
Chapter 11
Case Studies

11.1 The FARE Project by Fiat Auto

11.1.1 General Features

About 12 million cars are scrapped every year in Europe, of which 1.3 million in Italy. In front of these data the size of the problem linked to waste coming from junked cars emerges in all its significance.

It should be considered, however, that the metal parts of a car, about 75% of its weight, have been already recovered and recycled by the iron industry for a long time. The problem then arises for the remaining 25% made of plastics, rubber, glass, etc., and for which there have always been both technical and economic difficulties in recovery and recycling.

The attention of European manufacturers has therefore focused on this area, on the wake of the new trends which saw an increase in the manufacturer’s responsibilities in the final stage of production cycles.

Similarly to other European manufacturers, FIAT presented its own project, named F.A.R.E. (FIAT Auto Recycling), in 1991, aiming at completely salvaging and recycling the materials used to make cars.

The project is no longer in the experimental stage, but is actually and effectively operational. At first we will examine the preparatory steps, as well as checking the validity of the project itself, then its articulation and organisation, and finally its progress.

Before dealing with the more technical steps, it is necessary to explain which were the goals FIAT had set.

The research of an appropriate destination for the salvaged materials was considered essential, from which the primary need to find both technical and economically valid commercial outlets for such materials derived.

This aspect is of considerable importance. It would have been a paradox to design a material salvage system to avoid discarding in landfills, without foreseeing the actual possibilities for its reuse in other production cycles – which is what actually happened in Germany with packaging. Later we will check how this goal, which is of primary importance within the overall logic of the project, was achieved in real practice.

At first the flow of materials used by FIAT annually will be examined (Fig. 11.1). The figure shows a material input equal to 2,400,000 tons and two kinds of recycling going on: that of metals from junked cars, calculated in 1,300,000 tons; and that of both plastics and metals, from production scraps. The latter, in their turn, are subdivided into two flows: one included in the production itself, and the other one headed to the discarding and recycling system called Phoenix, previously dealt with.

The problem which remains open, and which is assessed around 500 hundred tons, is represented by the organic materials and glass coming from junked cars.

Within the types and quantities of materials used in a car (Fig. 11.2) the most interesting part is that 25% consisting of plastics, tyres and glass. Within this share, a special attention is paid to plastics owing to their percentage (10.4%) in the total considered.

The particular attention FIAT devotes to the problem of plastic salvage has various explanations.
First of all, the use of plastics in car manufacturing has progressively increased, rising from 1-2% of weight content in FIAT models in the ‘60s, to 10% in present models (Fig. 11.3). The reason for this increase in the use of plastic should be sought in the technical improvements it made possible (such as noise reduction, constructions free from sharp edges, etc.) and above all in its being cheap.

![Fig. 11.1 Material flow at FIAT](image1)

![Fig. 11.2 Types and quantity of materials used in car (%)](image2)

(Total 2,000,000 ton/year)
Plastic recycling, however, is difficult since it depends on the numerous types of materials used (Fig. 11.4).

In particular, the incompatibility among polymers series led to:
- a selective collection of components, based on the type of material;

Source: FIAT, 1992

Fig. 11.3 Plastics Growth in FIAT Cars

Source: FIAT, 1992

Fig. 11.4 Types and quantity of plastics in Fiat cars (%) (Total 2,000,000 ton/year)
- a study of recycling processes and the possibility of specific reuse for each material.

In assessing this last aspect another important factor had to be taken into consideration: the decay of the material properties due to ageing, that is, all those structural changes which take place during the use owing to functional and atmospheric agents (light, moisture, temperature, fuels, etc.).

It must be noted, however, that the situation described refers to component recovery of cars made 10-15 years ago, and which are now headed to scrapping. In fact, studies, also at a European level, have been carried out aiming at reducing the number of the polymer series, as well as the number of multi-material components, that is, made of hardly separable materials, in order to favour the recycling process in the future.

In spite of all difficulties, FIAT has devised a system for recycling plastic components, able to solve the problems mentioned. In particular, a marking system of all components weighing over 50 gr., complying with ISO standard, has been operational since 1992 in order to favour selective collection.

A “cascade” reuse system was studied in order to take into consideration the decay of the material properties due to use. The material recovered is reused in components requiring lower characteristics in comparison with the original application, both with regard to performance and appearance. Such criterion allows us to exploit the material residual properties at their best, avoiding additional costs to restore the original properties and ensuring, in any case, quality and reliability of the recycled components.

A concrete example of the cascade concept is given by bumpers. These, made almost completely in polypropylene, become, through shredding and re-granulating processes, raw material for simplest components such as the heater box, the air filter body, and the dashboard ducts.

The essential characteristic of this use, called of second generation, is ensuring the complete reuse of the recovered polymer material. This second important concept, identified by FIAT as “quantities balance” further confirms the main goal, previously mentioned, of the whole project, that is ensuring the complete reuse of salvaged materials, and the possibility of an outlet within car industry itself.

Where this result was not possible, uses in different markets have been provided, large enough to ensure the complete reuse of the same materials. It was the case of glass and seat foam which will be dealt with later.

Second generation components, arrived at end of life, may be further recycled to obtain other components having even lower functional characteristics, such as mat supports.

At the end of their life, third generation components may be reused to exploit their energetic content through combustion.

It is important to highlight the novelties introduced in this operation by FIAT, also with regard to the proposals of other manufacturers.

The solution originally proposed by BMW concerning bumpers was unsuccessful. The German manufacturer, in fact, solved the problem of plastic ageing, an irreversible physical phenomenon, by restoring its initial properties.

The idea was to obtain new bumpers for new cars from old scrapped bumpers. However, in order to accomplish this operation - which stirred a great deal of comments since it was understood as a sort of “perpetual motion” - toxic and hazardous additives must be added to the non toxic and non hazardous residue components of the old bumpers. The real problem was thus missed, being that of salvaging materials the critical factor of which was its size and not its toxicity or hazard. Adding new chemicals to the recovered component would thus lead to increasing pollution.

Another technical-functional aspect must be noted. The raw material, that is raw plastic, is and will be used by FIAT to manufacture security parts such as tanks and bumpers, to guarantee their reliability.

The same end-of-life material will thus be used to manufacture less important parts (e.g. air ducts) with the benefit of evident performance improvement, since the plastic used for their manufacture, coming from old bumpers, has quality features considerably higher than those of the plastic originally used.
With regard to the previously described energy recovery from plastics, it must be noted that although being technically feasible and effectively and ecologically safe, it still has some difficulties in the actual accomplishment.

FIAT studied a further use for this residue material, that is, the possibility of using powdered plastics as fuel in smelters (Fig. 11.5).

This solution proved valid also for fluff, the organic material (plastic, rubber, paint) coming from shredders of obsolete vehicles.

With this possibility of use as fuel - patented by FIAT – it is possible to exploit the high calorific value of plastics (Table 11.1) and reduce the amount of coal generally used.

**Table 11.1 Combustion energy**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Calorific Value (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>11,000</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>11,000</td>
</tr>
<tr>
<td>Polyamides</td>
<td>8,500</td>
</tr>
<tr>
<td>Abs</td>
<td>8,000</td>
</tr>
<tr>
<td>Elastomers</td>
<td>9,000</td>
</tr>
<tr>
<td>Fuels</td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>13,000</td>
</tr>
<tr>
<td>Coal</td>
<td>8,500</td>
</tr>
</tbody>
</table>

*Fig. 11.5 Energy of recovered plastics*
It is important to note how this further passage, which represents a real innovation world-wide, allowed us to achieve the target of recovering 100% of end-of-life cars, either as raw material or energy.

After having examined the main aspects of the project and the guidelines of the specific studies of process validation, particularly in the plastic sector, we wish to assess the technical and organisational aspects within the F.A.R.E system.

11.1.2 The Disassembly Experimental Centre

After having accepted the environmental challenge represented by the total recovery of junked cars, and having ascertained the real possibilities of accomplishment through a project aiming at reusing salvaged materials, it was necessary to define the technical and organisational aspects.

With regard to the more specifically technical aspect, in 1991 a study was carried out on the actual possibility of component disassembly.

To this end, a Disassembly Experimental Centre was set up at the Mirafiori plant in Turin, the purpose of which was prompted by the elaboration and definition of appropriate specific techniques on time and methods to disassemble the components of single car models and to select the levels to be maintained to ensure material recycling.

Subdivided in ecological stations and high value recycling stations (Fig. 11.6) the Centre aimed at checking methods and techniques to accomplish a car disassembly cycle, studying easy modes of disassembly and main component recovery, examining the system to identify and classify the plastics used in each car.

In particular the Centre examined the car models manufactured by FIAT in the last 20 years, arranging disassembly methods, time and tools for each one of them and for each component.

The operations which were analysed are those carried out in the ecological stations and those to make the vehicle environmentally safe, obtained by removing fluids and polluting components (fuel, lubricants, batteries, etc.). The following table (Table 11.2) highlights the elements to be removed with the relevant initial amounts and destination.

<table>
<thead>
<tr>
<th>Polluting fluids and components</th>
<th>Elements</th>
<th>Max. quantity</th>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Gasoline</td>
<td>40.42</td>
<td>Recovery station</td>
</tr>
<tr>
<td></td>
<td>Gas oil</td>
<td>46.20</td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>Engine</td>
<td>3.75</td>
<td>Used oil compulsory consortia</td>
</tr>
<tr>
<td></td>
<td>Change gear and differential</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Suspensions</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brakes</td>
<td>0.387</td>
<td></td>
</tr>
<tr>
<td>Liquids</td>
<td>Engine cooler</td>
<td>7.89</td>
<td>Exhaust battery comp. consortia</td>
</tr>
<tr>
<td></td>
<td>Windshield washer</td>
<td>2.85</td>
<td>Discarding stations</td>
</tr>
<tr>
<td>Other</td>
<td>Battery</td>
<td>2.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oil filter</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air filter</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brake lining</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td><strong>Max. Total</strong></td>
<td></td>
<td><strong>63.21 kg</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: Car Disassembly Experimental Centre, Fiat, 27.3.1992

With regard to the destination of the elements to be removed, there were no problems: batteries, oil, and liquids were sent to the respective compulsory consortia, fuel was recovered, while there was the need to discard (air and oil) filters, and brake lining, the polluting rate of which may be assessed.
at 1% (Table 11.3).

The methodology used to make the vehicle environmentally safe is that of directly discharging liquids from the parts which contain them, without disassembly, although they are not provided with discharging devices. To this end, tools were designed to make holes in the parts containing liquids and discharge them.

2. Operational flow

Car disassembly takes place in two different steps:
- Ecological stations
- High value stations

In the ecological stations the operations to make the car environmentally safe are carried out by removing fluids and other polluting components, whereas in the high value stations, disassembly is carried out for subsequent material use.
Table 11.3 Initial quantity of polluting components and fluids (% in kg)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Brake oil</td>
<td>0.60%</td>
<td></td>
</tr>
<tr>
<td>Change gear and differ. Oil</td>
<td>4.90%</td>
<td></td>
</tr>
<tr>
<td>Shock absorber oil</td>
<td>1.50%</td>
<td></td>
</tr>
<tr>
<td>Engine oil</td>
<td>5.90%</td>
<td></td>
</tr>
<tr>
<td>Windshield washer</td>
<td>4.50%</td>
<td></td>
</tr>
<tr>
<td>Engine cooler</td>
<td>12.50%</td>
<td></td>
</tr>
<tr>
<td>Air filter</td>
<td>0.40%</td>
<td></td>
</tr>
<tr>
<td>Oil filter</td>
<td>0.60%</td>
<td></td>
</tr>
<tr>
<td>Battery</td>
<td>4.10%</td>
<td></td>
</tr>
<tr>
<td>Brake lining</td>
<td>1.10%</td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>73.00%</td>
<td></td>
</tr>
<tr>
<td>Polluting Components</td>
<td>6.1%</td>
<td>3.96 kg</td>
</tr>
<tr>
<td>Polluting Fluids</td>
<td>93.9%</td>
<td>59.36 kg</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>63.21 kg</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: Car Disassembly Experimental Centre, Fiat, 27.3.1992

Destructive type actions, such as the one illustrate above, are explained by the fact that it is not necessary to ensure the vehicle parts functionality after the action. Moreover, such actions proved valid from the economic standpoint since they reduce processing time and equipment costs.

The following diagram (Fig.11.7) highlights the sequence of operation to make the vehicle environmentally safe with the relevant partial and progressive positions and time required.

Fig. 11.8, instead, illustrates the calculations of the total time and cost of labour. The discrepancy between the two figures is explained by the presence of operations, such as fuel drainage (operation no. 5), which do not require the presence of an attendant for the whole operation after the first necessary action.

The time taken by an attendant to carry out the operations to make the car environmentally safe is about 42 minutes. The total time taken to carry out the whole process is a little lower than one hour.

In high value recycling stations the operation of vehicle components disassembly was carried out for reuse. Table 11.4 below details the components which were removed, the initial amounts and the destination.

Table 11.4 Definition of components to be removed

<table>
<thead>
<tr>
<th>Recyclable Components</th>
<th>Elements</th>
<th>Weight (kg)</th>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>windshield</td>
<td>13.00</td>
<td>Glass Industry</td>
</tr>
<tr>
<td></td>
<td>Rear window</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Side windows</td>
<td>10.20</td>
<td></td>
</tr>
<tr>
<td>Plastics</td>
<td>Bumper</td>
<td>12.10</td>
<td>Chemical Industry</td>
</tr>
<tr>
<td></td>
<td>Dashboard</td>
<td>4.30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seat foam</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>Rubber</td>
<td>Tyres</td>
<td>21.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gaskets</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Precious Metals</td>
<td>Aluminium</td>
<td>24.40</td>
<td>Iron Industry</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>kg. 99.75</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Car Disassembly Experimental Centre, FIAT, 27.03.92.
The following Table 11.5 illustrates the types of materials used to make car model “Ritmo”.

The methodology used for disassembly of recyclable components is based on the same ideas developed to make the vehicles environmentally safe, by employing methods which make possible a fast disassembly also of the destructive type.

**Table 11.5 Types of materials for FIAT model “Ritmo” (% and kg)**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Weight (kg)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>30</td>
<td>3.6</td>
</tr>
<tr>
<td>Tyres</td>
<td>40</td>
<td>5.8</td>
</tr>
<tr>
<td>Plastics</td>
<td>76</td>
<td>9.1</td>
</tr>
<tr>
<td>Other (paints, protective coating)</td>
<td>42.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Precious metals</td>
<td>42.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Steel, cast iron</td>
<td>592.0</td>
<td>71.3</td>
</tr>
<tr>
<td><strong>Vehicle Total Weight</strong></td>
<td><strong>830 kg</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: Vehicle Disassembly Experimental Centre, FIAT, 27.03.92.

**Sequence of operations to make the vehicle environmentally safe with partial and progressive costs (1 attendant)**

1. Air filter removal
2. Battery removal
3. Windshield washer drainage
4. Rear window washer drainage
4a. Cooler drainage (1st stage)
5. Fuel drainage
6. Change gear and differential oil drainage
7. Engine oil drainage
A. Car loading on lift
8. Oil filter removal
9. Cooler drainage (2nd stage)
10. Brake oil drainage
11. Front brake friction lining removal
12. Rear brake friction lining removal
13. Front shock absorber oil drainage
14. Rear shock absorber oil drainage
15. Oil filter disposal (on line side)
B. Car unloading by lift

*Fig. 11.7 Car Disassembly Experimental Centre*
The above statement is explained by the fact that the components removed will not be put on the spare parts market later on, but they will be delivered to external industries to be reused as raw materials, through an accurate distribution logistic which will be examined later.

**Labour cost and time taken**

1. Air filter removal
2. Battery removal
3. Windshield washer drainage
4. Rear window washer drainage
4a. Cooler drainage (1st stage)
A. Car loading on lift
5. Fuel drainage
6. Change gear and differential oil drainage
7. Engine oil drainage
8. Oil filter removal
9. Cooler drainage (2nd stage)
10. Brake oil drainage
11. Front brake friction lining removal
12. Rear brake friction lining removal
13. Front shock absorber oil drainage
14. Rear shock absorber oil drainage
15. Oil filter disposal (on line side)
B. Car unloading by lift

**Labour Cost**

**Total time taken**

*Fig. 11.8 Car Disassembly Experimental Centre*
The following diagrams (Fig. 11.9 and 11.10) illustrate the sequence of disassembly operations, with relevant partial and progressive positions and time required.

The time taken by an attendant to carry out the operation previously illustrated is a little bit over one hour and a half. The total time to carry out the whole process is a little higher, the reason being the same as for the ecological stations.

11.1.3 The F.A.R.E. System

Once we had checked the possibility of going ahead with vehicle separate disassembly according to profitability criteria, and after having checked the possibilities of commercial outlets for the disassembled materials, it was necessary to create an industrial organisation able to manage the whole process.

To this purpose, FIAT entered an agreement with A.D.A. the Italian association of car dismantlers.

Among the reasons which prompted the manufacturing company to collaborate with dismantlers are worthwhile mentioning their organisation and capacity to carry out disassembly operations, as well as their being scattered all over the country, essential condition to ensure a widespread collection and minimise transport costs.

Sequence of operations to make the vehicle environmentally safe with partial and progressive costs (1 attendant)

16. Removal of propulsion system
16a. Car ground anchorage
17. Front bumper removal
18. Rear bumper removal
19. Dashboard removal
19a. Car release from anchorage
20. Windshield removal
21. Rear window removal
22. Front side windows removal
23. Rear side window removal
24. Fabric, seat foam, roof removal
25. Removal of gaskets from moving parts
26. Wiring removal
27. Separation of tyres from rims (line side)
28. Separation of aluminium parts (line side)

Figure 11.9 Car Disassembly Experimental Centre
The company choice to rely on operators scattered over the territory differentiates the F.A.R.E project from other ongoing experiments in this sector - see the Volkswagen. While for the German company the prospect is that of splitting the industry into a production branch on the one hand, and

Labour cost and time taken

16. Removal of propulsion system  
16a. Car ground anchorage  
17. Front bumper removal  
18. Rear bumper removal  
19. Dashboard removal  
19a. Car release from anchorage  
20. Windshield removal  
21. Rear window removal

22. Front side windows removal  
23. Rear side window removal  
24. Fabric, seat foam, roof removal  
25. Removal of gaskets from moving parts  
26. Wiring removal  
27. Separation of tyres from rims (line side)  
28. Separation of aluminium parts (line side)

Total Labour Cost

Figure 11.10 Car Disassembly Experimental Centre

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a dismantling and recycling branch on the other, FIAT just had to transfer its acquired disassembly
know-how to external facilities already existing.

A number of dismantlers were selected among A.D.A. members, 6 at first, now over 50, which
guaranteed reliability and compliance with environmental regulations.

A Disassembly Experimental Circuit was thus established, starting from Northern Italy and now
spread all over the national territory.

The dismantlers included in the circuit carry out disassembly of the following components ac-
cording to the directions provided by FIAT and on the basis of studies made by FIAT at the Experi-
mental Centre: bumpers and other plastic parts (belts, shanks), seat foam, glass.

For each one of these materials FIAT identified specific commercial outlets for recycling. In some
cases reuse occurs in the car industry (see bumpers) according to the previously described procedure,
in other cases in different markets (chemical and glass industries).

The companies participating in the circuit as recyclers are respectively Himont in Ferrara
(bumpers), Strapazzini in Pesaro (carpets) and Emiliana Rottami in Modena (glass).

At the end of the circuit, high value recycling of the bodies shall be included. These, free from
polluting materials, are given to Transider steel plant (Falk Group) for ferrous metals salvage.

The picture is finally completed by the industrial energy recovery of fluff. The Società Siderurgi-
ca Montello employs fluff to pre-heat ferrous scrap which will be subsequently melted in the electric
furnaces, saving the equivalent amount of fuel oil.

Operational since 1992, the F.A.R.E. system recycled 12,500 car in the same year and 25,000 cars
in 1993. The forecast for the current year shows a doubling of that figure, thanks also to the strengthen-
ing of the dismantler network.

The circuit operation, although still in a small scale, is illustrated in detail (Fig. 11.11).

First of all, dismantlers carry out the operations to make the car to be scrapped environmentally
safe, consisting in removal of battery and drainage of the various fluids, as we have already seen, tak-
ing care of their separate storage and subsequent delivery to the respective authorised recycling and
disposal Centres. Later they start to disassemble the components to be recycled.

The circuit (see Fig. 11.12) includes 5 material flows, three of which already operational and two
under way, concerning CFC and catalytic converters.

Bumpers and other plastic components are disassembled and stored separately by the dismantlers.
They are regularly collected by a special vehicle build by Himont, one of the major chemical indus-
tries in Italy. This vehicle takes care, on site, of roughly shredding the components, so as to increase
the quantity to be transported, and then of transporting it to Politec Company, in Bologna, entrusted
with the regeneration of the material. At Politec the material undergoes washing and floating treat-
ment - to separate polluting elements such as metals, stones, plastics or of other kind – it is then fur-
ther shredded and extruded in granulate which will be used for pressing new components. The mate-
rial thus obtained is then sent to the FIAT plant in Villastellone, where it is used for pressing dash-
board air ducts for “Tipo” models.

With regard to disassembly of seat foams, made of polyurethane foams, the dismantlers use fast
and economic techniques (cutting and quick separation of foams from lining).

The foam stored is then pressed on site through special presses which reduce volume of about 10
times, favouring transport from the dismantler’s to the recycling firm.

Material recycling takes place at the Strapazzini Company in Pesaro. There, the foam is finely
ground, resin is added to act as a binding agent, and the foam is pressed in the shape of big cylinders.
From these, mats of various thickness are obtained by cutting, to be used as under carpet for furn-
ishing, gyms flooring, tennis courts, etc.

With regard to glass, the dismantler takes care of its disassembly through crashing and collection
in appropriate containers. These containers are regularly picked up by a company specialised in glass
recycling: Emiliana Rottami from Modena. This company, one of the largest centres for scrapped
Fig. 11.11 The F.A.R.E. system

Source: FIAT
equipped both for separating glass form the plastic sheets contained in the windshield, and to select it and crash it to the granulometry necessary for its reuse. The material thus prepared is sent to the glass industry (among which Saint-Gobain company), where car windows become bottles and glass containers.

The bodies, thus stripped of recyclable elements, are sent to the shredding plant of Falk steel plants which, at present, is the largest in Europe with its 6,000 HP.

The bodies coming from the dismantlers of the F.A.R.E. Circuit are shredded, their greater economic value being acknowledged thanks to the lower amount of polluting elements present and the lower quantity of fluff generated.

After shredding, ferrous metals and light metals are sent to their respective metallurgical industries (steel plants and foundries).

The fluff originated, being free from glass, is mainly made of organic substances with a high calorific value. It is precisely to exploit this quality that the Montello iron industries have made a plant which makes pre-heating the ferrous material headed to the electric furnace possible. Fluff is then used as fuel to bring ferrous scrap to a temperature over 400 °C, operation by which about 30% energy saving is possible. With this last operation the target of 100% recovery of end-of-life cars is achieved, either as raw material or energy.

What emerges from the examination of the F.A.R.E. circuit is the fact that FIAT, actually, never participates in the operations directly. In fact, it only designed and accomplished the technical feasibility of the whole project, entrusting it to external operators who continue to have their own autonomy.

In particular we refer to dismantlers who, although participating in the F.A.R.E. project, maintain their autonomy by operating also out of the system. It is not, therefore, an exclusive relation, but a simple collaboration agreement with mutual benefit. The benefit for FIAT is that of avoiding the enormous costs implied by arranging its own dismantling centres. The benefit for the dismantlers is that of participating in an innovative project the evolution of which could be nothing but positive.

With regard to the relations with recycling companies, also in this case FIAT established a sort of contact, a link between dismantlers and the companies. FIAT, in fact, maintains direct contacts only with Politec since it is the supplier of the plastic used for air ducts of new cars. There are not direct commercial contacts with the other companies, given the incompatibility of the products dealt with by them.

On the contrary, specific commercial relations exist between recycling firms and dismantlers, with the former getting in touch with the latter to purchase material to be recycled.

11.1.4 The economic aspect and the project sustainability

After having examined the project’s technical and organisational aspects, we now deal with the economic aspect.

At the economic level the project target is to achieve self-financing, so that the choice of recycled components proves profitable also from the industrial cost standpoint. Which means, in other words, obtaining the same price for recycled and raw materials (Fig. 11.12).

The balance exists and it is really achieved if we included also the discarding cost among raw material costs.

In fact, in the light of what we said in the first paragraph on the trend to increase the manufacturer’s responsibility in the stage of product discarding, and also on the basis of the German experience with regard to packaging, we cannot avoid including the cost of discarding storage for end-of-life products, among the costs that affect the product final price.

The economic balance of the project is evident on the basis of these considerations, which must necessarily be assessed in an innovative project aiming at anticipating a greater strictness of regulations and heavier obligations for the manufactures.
A further confirmation of the project profitability derives from the analysis of the discarding cost trend (11.13). This assessment referred to Germany clearly shows that the cost trend for the final storage of discarded waste will undergo a considerable increase over the years, mainly due to the in-

![Fig. 11.12 Economic Target. Raw/Recycled material cost comparison](image)

![Fig. 11.13 Discarding costs trend (Germany)](image)

Source: FIAT, 1993
creasingly small space available and the constant action of environmentalists, as well as to the most modern environmental policies which view this solution as a menace to the ecological balance.

Other benefits are those of a lower dependency from the increasing need for raw materials and energy, besides the reduced environmental impact due to the lower residues generated.

With regard to the benefits arising for the single parts involved in the System, it is worthwhile mentioning that FIAT return cannot be considered of the economic type, at least not in its basic meaning, since it does not participate directly in the process.

The benefit for FIAT is mainly of image, in a field in which this is considered a strategic factor. All this will turn into an economic return in the medium term.

The fact that European competitors, among which Renault and BMW, have entered agreements to “import” FIAT model to their countries, proves the validity of the whole project.

We can undoubtedly say that at present FIAT image is that of the single company in Europe able to design and manage the complex problem of discarding end-of-life cars successfully.

The benefit for dismantlers, instead, are of two kinds: the first one is economic, since they sell recovered parts to recycling firms with profit; the second and maybe most important one is strategic. It consists in participating in a circuit well-known and advertised for the ecological ends it pursues. It also provides the possibility of a future participation, with FIAT, in bills which foresee the regulation of the whole sector of car dismantling, being subjects already present in a salvage circuit of proved reliability and regular activity organised by a company like FIAT.

The benefits for recycling firms are exclusively economic and consist in the possibility of purchasing quantities of materials, destined to increase progressively, at competitive prices.

To confirm the successful operation of the F.A.R.E. System, Table 11.6 illustrates the amounts of material processed in 1993.

As you can see the materials recovered from 25,000 junked cars reach almost 26,000 tons. These amounts, although representing a small part of the materials potentially recyclable from end-of-life cars in Italy every year, are however an example of recycling economically and technically valid.

Table 11.6 F.A.R.E. System: activity situation as at 30.1.94

<table>
<thead>
<tr>
<th>Dismantled Cars:</th>
<th>25,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycled Materials:</td>
<td>770 tons</td>
</tr>
<tr>
<td>(glass, plastic, seat foam)</td>
<td></td>
</tr>
<tr>
<td>Ferrous Metals Recovered</td>
<td>20,000 tons</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disassembled quantities (ton)</th>
<th>Reuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass 440</td>
<td>700,000 bottles</td>
</tr>
<tr>
<td>Bumpers 150</td>
<td>60,000 air ducts for Tipo and Punto models</td>
</tr>
<tr>
<td>Seat foam 180</td>
<td>200,000 sq. m of carpet</td>
</tr>
</tbody>
</table>

Source: FIAT, February 19994.

With regard to the possible future development within the system, the company’s target is that of providing a gradual enlargement of the circuit on the national territory, with a subsequent increase of the quantity of the materials processed as well as their quality. Mutual agreements are expected to be entered, besides the one already executed with Renault and BMW in April this year, to make possible the processing of cars from different manufacturers (Martinelli, 1994). The target is to reach through the exchange of technical documentation and information among manufactures – dismantling centres located in different countries, able to dismantle car components of different manufacturers efficiently and economically.

Another aspect in which FIAT has already carried out appropriate research, is that which foresees the increase in recovery of new components, such CFC and catalytic converters.
One last aspect to be considered, which will considerably affect the profitability and the development of the whole system, is that of a few necessary normative provisions. FIAT, in fact, proposed to set up a “dismantling certificate” holding which is the necessary condition to obtain cancellation from the Motor Vehicles Registry and subsequent cancellation of the motor tax.

Such certificate could be issued exclusively by authorised dismantling centres, the requirements and responsibilities of which should be determined through their certification by public bodies.

This instrument would be a means of control and guarantee of the system operation.

By implementing this normative and organisational contributions a system may be achieved which, besides being economically and technically feasible, would make a complete reorganisation of the car dismantling sector possible.

11.2 Automotive recycling in Nissan

11.2.1 Current situation on scrap vehicle in Japan

Fig. 11.14 shows the outline of car scrapping route in Japan. Shredding is performed after removing useful parts. About 70% of the materials are recovered in this process, and the remaining 30% becomes shredder dust, which is disposed of in landfills.

Disassembled parts and used cars are not only used in domestic market, but also exported to other countries. It is said that approximately 500 thousands used cars are exported to Asian countries and to some other countries.

Fig. 11.15 shows the transition in new cars registered versus old cars scrapped over the past ten years. As you see, new car sales rose sharply from 1986, as did the number of cars scrapped.

The number of cars being scrapped has nearly reached the limits of available treatment capacity, which is said to be about 4 to 5 million cars a year.

As one can see in Fig. 11.16, the amount of shredder dust has more than doubled over the past ten years. Over one-million tons of this dust in now produced every year. Shredder dust is for the most

![Fig. 11.14 Route of car scrapping in Japan]
part disposed of through landfill.
However there are very few landfill sites left around Tokyo. This lack of available sites has caused a dramatic increase in landfill disposal costs, which have now topped more than 100 dollars a ton some case.

Fig. 11.17 shows the composition of shredder dust in Japan. When measured by weight, plastics account for 27% of shredder dust: but when measured by volume, they make up about half of it. And the increase of shredder dust and percentage of waste plastics in it, may cause a serious problem in the future.

![Graph of shredded dust and landfill cost](image)

Fig. 11.16 Total Discharge of dust & landfill cost in Japan

![Graph of number of scrapped cars](image)

Fig. 11.15 Number of scrapped cars
Looking Fig. 11.18 at data gathered in 1988, of a total of 4.88 million tons of plastic waste, 57% was common waste and 43% was industrial waste. The amount of waste plastics discharged from scrapped cars can be estimated about 300 thousands tons.

Seventy-three percent of all plastic waste is disposed of and the remaining 27% is recycled. Almost all of that which is recycled is industrial waste. And 65% of plastic waste is incinerated in Japan.

Fig. 11.19 shows changes in the amount of plastic materials used in Japanese cars. The black line indicates the Japanese average, and black dots shows the cases in Nissan. At present, it is estimated that, on average, plastics account for 8% of vehicle weight. Before the 1980’s, plastics were mainly used for interior components.

**Fig. 11.17 Material Components of shredder dust**

**Fig. 11.18 Total Discharge of plastic waste and its treatment in Japan (1988)**
Entering the 1980’s, however due to the greater freedom of design they allow and their restorability, plastics become used for bumpers and other external parts.

When we think of the need to achieve better fuel economy by reducing vehicle weight or to improve productivity by integrating parts, it’s plain to see that there is much future potential for the use of plastics in automobile.

Therefore if it remains as it is the amount of dust which comes from scrapped cars will increase and almost nobody could treat it as environmentally friendly.

We think these situation is almost same as in Europe.

In view of the serious state of waste disposal in Japan, the Japanese government is now considering revising existing waste disposal and formulating new ones.

The Ministry of International Trade and Industry, and its subcommittee proposed guide-lines for the automotive industry. Fig. 11.20 shows the guidelines which will be applied to the car itself. They call for a basic examination of vehicle materials, structure, and manufacturing method. Innovations to facilitate material recycling and disposal can be made at the vehicle design stage. Reducing the amount of final disposal waste generated through manufacturing and for the recycling of waste plastics and reducing the amount of burnable waste through incineration and improvement of energy recovery.

![Fig. 11.19 Future trends of plastics application in Nissan](image)

The following automotive manufacturing measures will be studied to reduce the amount of final waste disposal and to promote the recycling of plastic waste.

1. Full consideration to waste recycling and reduction.
2. Reduction the amount of burnable waste through incineration and improvement of energy recovery (Plastic Waste).
3. Further development of raw material related technology and investigation of new re-usage areas (Plastic Waste).

**Fig. 11.20: Industrial Waste Guidelines for Automobile Factories by MITI**
11.2.2 Nissan’s current action on recycling

NISSAN’s way of thinking and our Current action on vehicle recycling are mentioned in following sentences.

Last August, Nissan set up a Recycling Promotion Committee (Fig. 11.21). It is presently studying how to proceed with technology development taking into account the global sense that is consideration the differences in vehicle scrapping and recycling conditions in Japan, North America, and Europe.

Fig. 11.22 shows the NISSAN’s internal recycling organization in Europe. NISSAN European Technology Centre, NISSAN Europe, NISSAN Manufacturing UK, NISSAN Motore Ibenca and some sales dealers all join together and work as a team to tackle this task.

Now, let’s take a look at what be needed to further promote recycling. In order for recycling to take root as a functional system in society, there are very simple conditions which must be met.

- First of all, we must realize economic balance as much as possible. That is
- To expand the market for recycling in another word we must look for a lot of applications for recycling.
- And to discover new technology which is suitable for recycling.

![Fig. 11.21: Organization of Nissan recycling Committee](image)

![Fig. 11.22: Organization of Nissan European recycling working group](image)
Finding ways to satisfy these conditions for cars which have already been produced and which will be produced is the key to advancing recycling.

To do this, it will be necessary to develop recycling technology and to build social infrastructure through which to apply it.

Fig. 11.23 indicates the technical issues for the plastic recycling. And these issues are classified into three technical domains.

What is important is to design cars in such a way that each material used can easily be recovered, and to expand the use of materials that can be easily recycled. Structures for easy dismantling, Marking on plastic materials, Simplification of material composition, might be important issues.

The most pressing area of technological development is material recycling, and application for recycled plastic materials. However, it is also important to develop energy-recovery technologies through waste incineration. Japan has a relatively suitable environment for incinerating waste, so trials for energy-recovery through shredder dust incineration have begun in Japan.

The circumstances surrounding waste disposal differ from country from country. It is necessary to deal with this problem based on particular circumstances in each country.

Fig. 11.24 shows some examples of recycling in Nissan.

This slide shows the disposal and recycling state of waste produced in Nissan’s manufacturing processes. On the left is the amount of waste produced, and on the right, details of recycling. Approximately 75% of the waste produced is recycled. We NISSAN have a incineration facility in some production plants and recycle the energy for vehicle manufacturing. We also own the Landfill.

Fig. 11.25 shows some examples of plastic recycling employed at Nissan. This is one such example of plastic recycling in production process. At Nissan we recycle bumpers and plastic tanks in our production line. These are examples of recycling at our parts suppliers. Here waste materials from other than the automobile are recycled and used to make parts.

This shows the examples of the material identification markings being applied to the main plastic parts. So far We put the marking along with internal specification.
Fig. 11.26 indicates NISSAN’s current activity on recycling. As you can imagine from the NISSAN’s recycling organization chart, NISSAN is now conducting this task from the global point of view.

As NISSAN could not solve this task alone, we have already set up means of cooperating with our current suppliers. From this relationship we will reach better results as both of us are working together on the question.

We started to apply the material coding along with VDA260.
We are going to reduce shredder dust & recycle the waste in the manufacturing plant further more.
To facilitate the dismantling of plastic parts we’ll develop an easy dismantling structure and process.

Recycling in the Production Process
- Parts: Washer Tank, Wiper Parts, RR Combination Lamp, Heater Case, Cooler Case, Blower Case, PP Bumper, Radiator Reserver Tank
- Materials: PP, POM, ABS, AAS, PMMA, ASPE

Application of the Recycled Plastics
- Parts: Fusible Insulator, Floor Insulator, Cushion Pad, Door Trim Base, Floor Mat, Trunk Trim, Engine Under Cover

Identification of Plastic Materials by Marking
- Parts: Bumper, Radiator, Grill, Fender Protector, Engine Under Cover, Heater Case, Cooler Case, Blower Case, A/C Duct
- Materials: PP, PE, PUR, ABS, PC

Fig. 11.25: Examples of Plastic Recycling in Nissan
We will expand the application of recycled material such as PP and increase the recyclable material.

1. To promote Recycling Activity from the Global point of view
2. Co-operation with Suppliers
3. Materials Coding along with VDA 260
4. Recycling & Reduction of Manufacturing Waste
5. Development of Easy Dismantling Structure & Process
6. Increase of Recycled Material (PP etc.) & Recyclable Material

*Fig. 11.26: Nissan’s Current Action Items for Vehicle Recycling*
References


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