Research of the EU automotive industry into low-carbon vehicles and the role of public intervention

T. Wiesenthal, G. Leduc, J. Köhler, W. Schade, B. Schade
The mission of the JRC-IPTS is to provide customer-driven support to the EU policy-making process by developing science-based responses to policy challenges that have both a socio-economic as well as a scientific/technological dimension.
Research of the EU automotive industry into low-carbon vehicles and the role of public intervention

Tobias Wiesenthal\textsuperscript{1}, Guillaume Leduc\textsuperscript{1}, Jonathan Köhler\textsuperscript{2}, Wolfgang Schade\textsuperscript{2}, Burkhard Schade\textsuperscript{1}

\textsuperscript{1} IPTS, JRC, European Commission, Spain
\textsuperscript{2} Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany
# Table of content

1. Introduction ................................................................................................................... 5
2. The automotive sector as R&D investor ......................................................................... 8
3. How much does the sector invest in GHG emission reduction technologies? ................. 12
4. Which are the technologies favoured in the research of the automotive sector? ............ 15
5. Public R&D investments and the role of public intervention ......................................... 18
   5.1 Public R&D investments in road transport vehicle technologies .................................. 18
   5.2 Stimulating innovation in the automotive sector .......................................................... 20
   5.3 Steering research by regulation ..................................................................................... 20
   5.4 Creating market demand ................................................................................................. 23
6. Conclusions .................................................................................................................. 24
7. References ................................................................................................................... 26
1 Introduction

The European Union is committed to reduce its greenhouse gas (GHG) emissions by at least 20% by the year 2020 compared to 1990 levels in order to fight global climate change. In the long run (2050), there is an agreement that developed countries will need to bring down their emission levels by some 60-80% compared to the same base year.

While over the past decade most sectors managed to reduce their GHG emission levels, transport emissions experienced a continuous rise. By 2007, its GHG emissions were 36% above their 1990 levels, meaning that transport was responsible for almost one quarter of the overall European GHG emissions (European Commission, 2010). Even though emissions from civil aviation or total navigation have been growing faster than those of road transport over this period, the latter still account for more than 70% of all transport emissions.

The transport sector – and herewithin road transport – will therefore need to undergo significant changes in order to become more sustainable and to not endanger the fulfilment of the European climate and energy objectives. The European Union aims at achieving emissions of new passenger vehicles of 120 g CO₂/km by 2015. To this end, the average emissions of the new car fleet sold in Europe shall not exceed 130 g CO₂/km¹ by that time, which shall be achieved by means of improvement in vehicle motor technology. A further reduction of 10 g CO₂/km, or equivalent if technically necessary, will be delivered by other technological improvements and by an increased use of sustainable biofuels. The latter are further promoted through the renewable energy directive (2009/28/EC) that prescribes a mandatory 10% share of the final energy consumption in transport to be met from renewable sources by 2020. For the year 2020, the average emissions of the new registered vehicle fleet shall not exceed 95 g CO₂/km.

---

¹ Regulation 443/2009
While in the long run, modifications in urban planning and changes in the infrastructure have the potential to play an increasing role in reducing transport demand, in the short run technological changes (including the use of alternative motor fuels) are expected to take over a major role in reducing the environmental impacts of transport. Yet, reductions in weight and of aerodynamic and rolling resistance combined with improvements in the efficiencies of conventional powertrains alone may not be sufficient for meeting the 2015 and even less so the 2020 target (Fontaras and Zamaras, 2010). Also the results of the FP6 co-funded iTREN-2030 project confirm that the transport sector falls behind the envisaged reductions in GHG emissions even in the 'integrated scenario' that considers implemented and adopted policies, in particular when considering the 2030 time horizon (Schade et al., 2010).

Researching and developing new technologies such as electric or hydrogen-powered vehicles has therefore become a central challenge for the (European) car manufacturers. This challenge comes at a time when the automobile industry is facing increasing pressure due to the economic downturn and the high competition, even though the situation seems to have improved compared to a year ago.

The question arises whether industry alone will be able to mobilise the necessary efforts that can help them in meeting their environmental targets under the (new) situation of low profitability. Or whether there is a need for rising public support towards the development of innovative low-carbon technologies, just as the European Union has started it in the energy sector with its Strategic European Energy Technology Plan (SET-Plan2).

---

2 In November 2007, the European Commission published the Communication ‘A European Strategic Energy Technology Plan (SET-Plan)’, COM(2007)723 final, which forms the technology pillar of the European climate and energy strategy. As part of its implementation the Communication on ‘Investing in the Development of Low Carbon Technologies (SET-Plan)’ (COM(2009)519 final) was published in 2009. Besides, the SET-Plan Information System SETIS has gone online. Currently, a number of European Industrial Initiatives are implemented.
To this end, the present paper will analyse the European automotive sector and its current R&D investments\(^3\) for the year 2008\(^4\), investigating whether the sector mobilises adequate research efforts. We will then estimate how much of these efforts are directed towards the goal of reducing GHG emissions of the sector. Focusing on innovation on road vehicle engine technologies, we will go one step further and examine how much is currently being invested in research on promising low-carbon technologies, i.e. improvement of conventional engines, electric and hybrid vehicles, hydrogen/fuel cells and biofuels. In a next step, the role of public R&D efforts will be researched.

Key findings of the analysis shall be compared to the energy sector to the extent possible. Both sectors have in common that they are among the largest emitters of GHG\(^5\) (European Commission, 2010). Furthermore, scenarios indicate that with current technologies, long-term climate targets cannot be met, demonstrating the need for researching and developing further low-carbon technologies in both sectors. The EU therefore aims at stimulating the development of low-carbon energy priorities through its Strategic Energy Technology Plan. The question arises, whether a similar approach would be appropriate in the transport sector, given the very distinct nature of innovation in energy and transport. Hence, the comparison with the energy sector can provide some insights in the need and possible direction of a Strategic Transport Technology Plan.

Note that the use of R&D investment as the only indicator for research and development activities in a technology certainly falls short of the complexity of problems encountered by innovators in the energy sector (Sagar and Zwaan, 2006). Innovators face a number of adverse effects which reduce the incentives for innovations (e.g. market spillovers, knowledge spillovers and network spillovers; see e.g. Jaffe et al., 2005). A framework for assessing these barriers would need to go far beyond the analysis of financial support to transport research, but needs to include an assessment of institutional capacities, policies and measures and their use and interplay (Fri, 2003), as it is done in the concept of the Innovation System. Nevertheless, the analysis of R&D investments can help in better understanding the status of one central step in the innovation cycle and thus justifies its use here.

Parts of the following assessment draw on on-going work undertaken in the context of the FP7 project 'GHG-TransPoRD'\(^6\). Both the methodology and results will be described in more detail in the forthcoming report D1 of that project.

---

\(^3\) R&D investments on road infrastructure are not considered.

\(^4\) Available data did not allow for the analysis of more recent developments. Considering only 2008 data means that major public support programmes taken in the context of the economic crisis have not been included.

\(^5\) Energy industries (i.e. public electricity and heat production, petroleum refining and other energy industries) accounted for around 32% of the total GHG emissions in EU27 in 2007 (European Commission, 2010).

\(^6\) [www.ghg-transpord.eu](http://www.ghg-transpord.eu)
2 The automotive sector as R&D investor

The automotive sector shall be defined as follows, based on the ICB (Industry Classification Benchmark) classification\(^7\):\(^8\):

- 'Automotive manufacturers' (part of 'Automobiles & parts')
- 'Automotive suppliers' (part of 'Automobiles & parts')
- 'Commercial vehicles and trucks'

Where appropriate, we have included available information on 'aerospace and defence' and 'all industries', which can be used for comparison. Note that 'European company' in the following means a company with their registered office being in Europe, which may differ from the operational or R&D headquarters in some cases. Data is largely based on the EU Industrial R&D Investment Scoreboard\(^9\) (DG RTD-IPTS, 2009), which contains the 1000 top EU-based industrial R&D investors and the 1000 top non-EU based R&D investors.

In 2008, the European automotive industries included in the Scoreboard achieved a turnover of €645 billion, corresponding to around 11% of the total turnover and employees of all European industries of the Scoreboard. At the same time, the automotive industry invested almost €33 billion in R&D activities, around one quarter of the total industries' investment, and represents the largest private investor in R&D in Europe\(^10\). Note that the corresponding figures for the entire sector will lie above this, given that this is based on the 65 major R&D investing companies in these sectors, hence neglecting smaller R&D investing companies. This demonstrates the relatively elevated R&D intensity of this sector relative to other sectors, reaching around 5% of the turnover. In particular, it compares to the low R&D intensity of companies active in the electricity sector (0.6%) and oil and gas producers (0.2%).

---

\(^7\) We have split the 'Automobiles & parts' category into the two subsectors 'Automotive manufacturers' and 'Automotive suppliers'. Note that in the ICB classification 'Automobiles & parts' is generally divided into 'Automobiles', 'Auto parts' and 'Tires'. In this chapter, tire manufacturers are assumed to be part of 'Auto parts' as key companies in this group carry out R&D activities that go well beyond tire manufacturing.

\(^8\) Other ICB categories may include important companies playing a key innovation role to one or several transport modes. It is the case for instance of energy suppliers (e.g. biofuel, hydrogen, battery producers) as well as Siemens ('Electric components & equipment').

\(^9\) The EU Industrial R&D Investment Scoreboard is prepared from companies' annual audited reports and accounts and collects data on R&D investment for 1000 EU-based and 1000 non-EU based companies that are grouped according to the ICB classification.

\(^10\) Followed by the aggregated sector 'Pharmaceuticals and Biotechnology' with €21.3 billion invested in 2008. At world level, both sectors (i.e. 'Automotive' and 'Pharmaceuticals and Biotechnology') presented similar R&D investments in 2008.
Table 1: R&D investments, sales and total number of employees of companies included in the EU Scoreboard related to the 'automotive' sector (2008), 'aerospace and defence' and all industries

<table>
<thead>
<tr>
<th></th>
<th>R&amp;D investment (€bn)</th>
<th>Sales (€bn)</th>
<th>Number of employees (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>World</td>
<td>EU27</td>
<td>World</td>
</tr>
<tr>
<td>Automotive manufacturers</td>
<td>53</td>
<td>20.9</td>
<td>1213</td>
</tr>
<tr>
<td>Automotive suppliers</td>
<td>19.6</td>
<td>9.5</td>
<td>437</td>
</tr>
<tr>
<td>Commercial vehicles and trucks</td>
<td>6.9</td>
<td>2.4</td>
<td>233</td>
</tr>
<tr>
<td>Automotive industry</td>
<td>79.5</td>
<td>32.8</td>
<td>1883</td>
</tr>
<tr>
<td>Aerospace &amp; defence</td>
<td>15.6</td>
<td>7.5</td>
<td>379</td>
</tr>
<tr>
<td>All industries</td>
<td>431</td>
<td>130</td>
<td>13897</td>
</tr>
</tbody>
</table>

Source: derived from the EU Scoreboard 2009 (DG RTD-IPTS, 2009) (rounded numbers)

Note: The table shows the aggregated figures for 65 EU-based and 140 worldwide companies related to the automotive sector.

Surprisingly, the R&D intensities of the various sub-sectors that form the EU 'automotive industry' lie within a relatively narrow range of 3.6-6.2% for the various sub-sectors. Even with the R&D intensities of the automotive suppliers being the most elevated ones, they are only 1.2 percentage points above those of the car manufactures. Unlike for the energy sector, where large parts of the research are being carried out by companies other than traditional energy companies, but active in the supply chain (Wiesenthal et al., 2008, 2009), innovation in the transport sector seems to be undertaken on more or less equal levels from companies active at various parts of the supply chain. Following the taxonomy of Pavitt (1984), the automotive sector may thus be classified as 'Production intensive, scale intensive' sector, which is characterised by a combination of relatively elevated innovation in-house and from suppliers. This is in stark contrast to the energy conversion sectors, which are 'supplier-dominated', meaning that innovation mainly happens at the level of component suppliers.

The importance of innovation in the automotive sector can partly be explained by the sector being exposed to a 'differentiation and branding pressure' and innovation may be one of the 'selling factors' of vehicles. On the contrary, electric utilities produce a homogenous good with price competition being the main success criterion.
The above reasoning also provides some explanations on the rising R&D intensities of the automotive industry between 2002 and 2008 compared with the more or less stable R&D intensities in energy sectors (Figure 3). Increasing environmental pressure and rising consumer awareness (both for environmental and efficiency characteristics of new vehicles) are likely to have been a factor behind the increase of R&D intensities in the automotive sector. At the same time, the low – and even slightly decreasing – R&D intensities in the energy sector can partially be attributed to its relatively recent liberalisation. With the liberalisation of the markets\(^{11}\) and the accompanying rising price pressure and reduced ‘monopolistic rents’, private R&D activities in the electricity sector have decreased\(^{12}\) (see e.g. Eurelectric, 2003; Jamasb and Pollitt, 2005).

Of course, from this the question arises whether competitive markets will lead to sub-optimal R&D input and output (as argued by Jamasb and Pollit, 2005) or whether liberalisation may ultimately be positive, following the logic that innovation can lead to competitive advantages (Sanyal and Cohen, 2005). Aghion et al. (2005) found that neither perfect competition nor monopolies are optimal in terms of delivering innovation and that the relationship between the level of competition and innovation takes the shape of an inverted U. A recent paper of the ITF (2010) shows that the automobile industry, which can be described as a monopolistically competitive industry, would lie more or less at the top of the inverted U-curve, hence show strong innovation efforts. This is in line with the R&D statistical findings above.

---

\(^{11}\) However, the overall impact of liberalisation on innovation is not straightforward and there are opposite effects, described e.g. in European Commission (2006).

\(^{12}\) Note that R&D expenditures or activities are often used as a proxy for innovation, which is not necessarily the case. Furthermore, a reduction in R&D expenditures may also include an abolishment of inefficiently high or ill-directed expenditures (European Commission, 2006).
When positioning the European automotive sector in its global framework (see Table 1), two evidences appear: Firstly, the EU-based companies in this sector hold a large part (slightly above 1/3 in terms of net sales) of the global market. Secondly, EU-based companies seem to invest more in R&D than their non-EU counterparts; they finance more than 40% of the overall global R&D investment of the sector, followed by Japan and US-based companies (Figure 4).

Figure 4: R&D investments of the automotive sector of companies based in the EU-27, Japan, USA (2008)
Data source: EU Industrial R&D Investment Scoreboard (DG RTD-IPTS, 2009)

Key message 1: The automotive industry is the largest R&D investor in the EU-27, accounting for one quarter of total industrial R&D investments. Both car manufacturers and component suppliers show elevated R&D intensities with an increasing trend over the past years. Theory supports the analysis of the automotive sector being prone to a high innovation effort. The arising question is now how much of this effort is directed towards reducing the GHG emissions of the sector.
3 How much does the sector invest in GHG emission reduction technologies?

A key question is how much out of the more than €30 billion invested by the automotive industry in R&D activities is directed towards technologies that can help achieving the GHG emission reduction targets. Unfortunately, this question cannot easily be answered as data on corporate R&D investments become scarce at this level of detail (see e.g. Wiesenthal et al., 2009; de Nigris et al., 2008; van Beeck et al., 2009). No regulation obliges private companies to report their R&D investments, unless they are listed on the stock-markets and thus need to present their financial accounting and an annual report. The R&D investments included in these documents, however, are usually not specified further by field of activity or technology. The limited data availability can be explained by the fact that some companies consider this information as confidential, and that others use them for strategic purposes (Gioria, 2007).

In order to nevertheless obtain a rough estimation of the R&D investments of industry dedicated to different vehicle technology groups, a bottom-up approach has been followed\(^\text{13}\) (see Wiesenthal et al., 2009).

1. Firstly, the key industrial players investing in a certain technology have been identified, going beyond the traditional 'automotive sector', but including companies of relevance from other ICB sectors.
2. For these companies, total R&D investments were collected, usually from the EU Industrial R&D Investment Scoreboard (DG RTD-IPTS, 2009).
3. Based on other sources of information, such as annual reports, speeches etc., the parts of the company's R&D investment that is not dedicated to transport, has been removed (which is important for large multi-business companies e.g. Bosch, Volvo).
4. In a following step, the R&D investments have been further allocated to various modes and single technologies, based on an assessment of patents\(^\text{14}\), speeches, annual reports and other indirect indications such as the turnover of business sections or division or number of R&D employees by business segment etc.

Due to important data gaps in basic data and the subsequent need to approximate missing information in order to derive results at the EU-level, the results shown are associated with important uncertainties. Hence, its outcome can only provide a rough indication of the R&D efforts by technology.

---

\(^{13}\) The approach and underlying data and assumptions are explained in detail in the (forthcoming) deliverable D1 of the FP7 project GHG-TransPoRD.

\(^{14}\) Methodological problems related to the use of patents as an indication of R&D investments are discussed in detail in Wiesenthal et al. (2010, with further references).
The bottom-up approach means that instead of focusing on companies following the ICB classification as done above (section 2), a company-by-company assessment has been undertaken, including also relevant companies from ICB sectors that do not fall under the categories subsumed under 'automotive industry'. In total, around 50 companies have been identified as most relevant R&D investors on this topic, with the top 12 accounting for 90% of their aggregated R&D investment (Figure 5).

These 50 most important players invested €311 billion in R&D on road transport vehicles by 2008. For each individual company, assumptions on the allocation of their R&D investment to 'technologies for reducing emissions of GHG and air pollutants' and 'other objectives' have been made, based on indirect indications. However, unlike for the allocation of R&D investments to single technologies as undertaken in section 4, the broad number of technologies subsumed under this category did not allow for the use of patents as one quantitative indirect indicator. We estimate that industry allocated around €13 billion in research focusing on technologies to reduce GHG and air pollutant emissions in 2008. This corresponds to 43% of the total R&D investments.

This is supported by scattered evidence that can be found for single companies. Most of the automotive manufacturers and suppliers agree to say that a 'large share' or 'most of' the corporate R&D investment is allocated for improving the vehicle energy efficiency and then reducing greenhouse gas emissions. For instance, ACEA reported that 'A large part of the R&D investments is spent on technologies to reduce emissions of greenhouse gases such as carbon dioxide (CO₂), improving engine efficiency and performance'. T. Weber (Daimler) reported that Daimler spent €4 billion in R&D of which half going to green technologies, CO₂

---

15 This figure is slightly below the one reported in table 1 above, as it considers a more limited number of companies only, and removes the R&D parts that are not dedicated towards 'vehicle research'. At the same time, however, R&D efforts towards road transport are included from companies from other ICB sectors.
emission reduction and Euro 6 standard\textsuperscript{16}. At Volkswagen and BMW, 'one in every two Euros goes into environmentally friendly technologies'\textsuperscript{17}. C. Ghosn (Renault) claimed that the Alliance Renault-Nissan allocated one third of its R&D expenditures to clean vehicles, with the priority going to zero emission vehicles\textsuperscript{18}. In November 2009, G. Faury (PSA Peugeot Citroën) declared that the PSA group will allocate more than half of its R&D expenses over the period 2010-2012 towards new technologies for reducing CO\textsubscript{2} emissions and pollutants\textsuperscript{19}. At global level, a recent study from the consulting group Oliver Wyman reported that 'today, automakers are already investing about one-third of their worldwide research and development expenditure of some Euro 75 billion on this goal on these efforts, which include both further optimizing traditional combustion drives and developing alternative drive technologies for serial production. In the next ten years, investments in reducing carbon dioxide worldwide will total around Euro 300 billion – of which Euro 50 billion will be spent on alternative drive systems like hybrid or electric.'\textsuperscript{20} With regard to patent applications of the automotive sector, the German Association of the Automotive Industry (VDA) stated that 'On average, the German automotive industry applies for ten patents daily, a good half of which are in the field of environmental engineering'\textsuperscript{21}. Overall, these announcements confirm that the share of R&D spending allocated to technologies that reduce emissions of GHG and air pollutants is in the order of some 40-50% as found with the bottom-up approach applied in the present paper.

In order to further narrow down this figure on 'technologies to reduce GHG emissions', the part dedicated to research in technologies that reduce air pollutant emissions has been estimated and removed, based on a keyword-based research of the Espacenet patent (application) database. The results indicate that industry invested around €10-11 billion on R&D on 'GHG emission reduction technologies' by 2008, about one third of the total investment volume of R&D in road vehicles.

There is no comparable figure to this in the energy sector. A recent report found that industry invested €1.7 billion in 2007 in non-nuclear SET-Plan priority technologies (Wiesenthal et al., 2009). However, this sum does not include any investment in energy efficiency, nor does it cover all bioenergy-related R&D but only the biofuels-related parts of it. Despite the difference in scope, a rough comparison indicates that the investments undertaken by the automotive industry in technologies to reduce GHG emissions are elevated.

**Key message 2: R&D efforts in road transport largely concentrate on few industrial players. Out of their overall R&D investments, about one third is dedicated to technologies that reduce emissions of GHG, some €10-11 billion. This is much above the energy sector's industrial R&D investments in low-carbon energy technologies.**

\textsuperscript{17} http://www.atlantic-times.com/archive_detail.php?recordID=1460
\textsuperscript{19} Interview of G. Faury (27/11/2009) about the PSA vision on CO\textsubscript{2} emissions reduction, originally released by the Financial Times. http://www.ccfa.fr/article87729,87729.html
\textsuperscript{20} Oliver Wyman study 'E-Mobility 2025' (September 2009) http://www.oliverwyman.com/ow/pdf_files/ManSum_E-Mobility_2025_e.pdf
\textsuperscript{21} VDA, Annual Report 2009 available at http://www.vda.de
4 Which are the technologies favoured in the research of the automotive sector?

Following the bottom-up approach sketched out above, an estimation of the R&D investments into various transport-related low-carbon technologies has been undertaken. As mentioned earlier, obtaining figures at this high level of details is difficult and is largely based on expert assumptions and indirect indications; hence, the results are associated with significant uncertainties. An overview of the results is provided in Table 2.

Industry still provides the largest R&D support to the (efficiency) improvement of conventional internal combustion engine (ICE) technologies, given that these measures are considered to still have a large potential in the short term (Fontaras and Samaras, 2010). Corporate R&D investments in these technologies amounted to some €5-6 billion by 2008, around 16-20% of the total R&D investments of the automotive industry.

The second most important research topic, when considering industrial R&D investments as main indicator, is the development of electric vehicles (EV), including hybrids (HEV), plug-in hybrids (PHEV) and battery electric vehicles (BEV). Our rough estimates indicate that in 2008, around €1.3-1.6 billion, i.e. 4-5% of the total R&D investment volumes, were invested in this group of technologies centered on the electric powertrain.

Significantly lower research investments can be identified for alternative motor fuels such as biofuels or hydrogen. Note, however, that the scope of the analysis for these technologies has been widened to also include e.g. large oil companies, specialised biofuel producers or dedicated fuel cell makers on top of the automotive industry and its supply chain (such as battery manufacturers). This reflects the importance of these players in those technologies that go far beyond the vehicles powertrain but include substantial research on the side of fuel conversion. Hence, the results cannot directly be compared with the other figures shown above that focus on the automotive industry, even though we consider that no major changes would have occurred in the results for EV and conventional measures if R&D efforts from companies beyond the automotive industry had been considered.

Corporate R&D investments into transport biofuels amounted to some €0.3 billion in 2007 (Wiesenthal et al., 2009). In the same year, industry invested around €0.3-0.4 billion in fuel cell-related research, including both mobile and stationary fuel cell applications. In addition, more than €0.1 billion are invested in research on hydrogen production.

The ranking of corporate R&D investments with clear priorities given to the improvement of conventional engine technologies and electric vehicles rather than fuel-cell vehicles (and the exactly opposite ranking of public R&D investments, see below) can be explained by innovation theory. In general, technologies that are close-to-market and thus require expensive pilot plants and up-scaling would face larger industrial contribution, while technologies that are further from market are mainly publicly financed as industry would not want to take the risk. Having in mind that hydrogen-fuelled fuel cell vehicles (FCV) are not likely to enter the market in large quantities soon, the limited corporate R&D investments

---

22 Biofuels research is an exception in the sense that most of the R&D efforts are undertaken outside of the automotive industry. Moreover, the results shown above relate to the year 2007; at that time, conventional biofuel production was already mature, but the need for (and R&D in) advanced 2nd generation biofuels has become more pronounced thereafter.
dedicated to them do not come as a surprise. Nevertheless, FCV are seen as a strategic long term option also over battery vehicles for longer range vehicles (see Thomas, 2009; Campanari et al., 2009; Offer et al., 2010). This explains that industry keeps investing in them. Considering that privately funded R&D tends to be biased towards short-term results (NCEP, 2004), it is important for the public sector to ensure that sufficient attention is being given to also to promising long-term technologies.

While the above assessment of R&D investments only provides a snapshot for a certain year, a simplified analysis of patent applications can more easily be done for a time series and can thus help to understand the dynamics of research by technology. To this end, we have undertaken a simple analysis of the number of patent applications in the automotive industry over the period 1990-2009, using data from Espacenet provided by the European Patent Office23. This keyword-based search of patent applications follows the methodology described in detail by Oltra and Saint Jean (2009a)24 (unlike the more thorough, category-based patent analysis that has been used as one of the indication of the R&D breakdown above).

A steep increase in patent applications from the principal EU-based automotive manufacturers and suppliers on electric vehicles (including hybrids) becomes obvious. This hints at the rapidly growing importance paid by industry to the development of these technologies in recent years, supporting the conclusion of the technology’s importance that was drawn from the assessment of R&D investments above. At the same time, the patent applications on FCV are somewhat less, and rise much less rapidly. This general trend does not mean that hydrogen- and fuel cell related R&D activities have been stopped25. It rather indicates that they have become a lower priority for EU-based companies in the sector when compared to electric vehicles.

23 http://ep.espacenet.com/
24 Relevant analyses of patent applications from the automotive industry have also been carried out by Oltra and Saint-Jean (2009b) for the French automotive industry; Frenken et al. (2004) for the U.S. automotive sector in general. The FP6 project 'Measuring eco-innovation' (MEI) provides relevant inputs on this topic (see e.g. Oltra et al., 2008).
25 The R&D in H2/FC vehicles is on-going is underlined e.g. by Daimler (and the non-EU based companies Ford and Toyota), who confirmed their commitment to this technology and foresee that the technology will be for sale around 2015 (Hybridcars.com, 2009).
Figure 6: Annual number of patent applications related to electric vehicles (hybrid and battery electric vehicle technologies) and fuel cell vehicle technologies from the EU automotive industry over the period 1990-2009

Source: own analysis resulting from a keyword-based search, following the methodology of Oltra and Saint Jean (2009a)

Key message 3: The EU-based automotive industry directs a significant part of its R&D investments towards the improvement of conventional engine technologies and the development of the electric powertrain. Corporate R&D investments are significantly lower for long-term options such as fuel cell vehicles. A rough analysis of patents supports the growing importance of EV, showing a steep rise in the number of patents in this field, while patents on FCV are stagnating. This points to the need for public efforts to ensure that research in promising long-term options is not neglected.
5 Public R&D investments and the role of public intervention

In general, innovators face a number of spillovers\(^{26}\) that act as a disincentive to innovation, implying that R&D investments remain below the societal optimal levels\(^{27}\). In the case of low-carbon technologies, knowledge spillovers are combined with the still not complete pricing in of environmental externalities, which implicitly favours carbon-intensive technologies (Jaffe et al., 2005). Public intervention is therefore justified when it either stimulates industrial innovation – or complements industrial efforts with public R&D – in order to bring it to societal optimal levels, or when it steers innovation into better delivering to agreed policy goals (see ITF, 2010).

In the following, we will firstly assess current public R&D investments in road vehicle technologies (section 5.1). The next step then considers whether there is a general need for stimulating industrial innovation of the automotive sector (section 5.2). Section 5.3 assesses the possibilities for guiding existing industrial research efforts so as to best contribute to long-term policy targets. As research is only apart within the much broader process of innovation, section 5.4 will look beyond efforts aiming at increasing/steering R&D and address market demand measures.

5.1 Public R&D investments in road transport vehicle technologies

Available supranational data sources such as the IEA RD&D statistics or the Eurostat GBAORD do not allow for a comprehensive analysis of public R&D funds that would match the detail of the assessment done for corporate R&D investments above. Hence, to the extent possible data from national sources has been accessed\(^{28}\), and R&D funds have been allocated to the various technologies based on the limited information available. As data has been available only for 13 Member States\(^{29}\), the figures shown below are under-estimated. This is even more so the case as institutional funding is often excluded from the data obtained, even though parts of it is relevant for vehicle technology research. Furthermore, regional funds may not be systematically included for some Member States.

In addition to the public funds by EU Member States, relevant R&D support at the EU level has been considered, largely focusing on the contributions through FP7, and annualising them over the duration of the programme.

Table 2 below shows the estimated R&D spending from public national governments and at the EU level and sets them into context with the corporate R&D investments discussed above. Despite the fact that the figures on public R&D investments on road vehicle technologies are

\(^{26}\) Innovation efforts from the private sector are often limited due to risk aversion, freerider concerns and the need for making short-term profits.

\(^{27}\) See e.g. Wiesenthal and Saveyn, 2009 on innovation in the energy sector with further references.

\(^{28}\) In addition to the IEA RD&D and GBOARD databases, the following sources have been used: the EAGAR project that by the time of writing provided an analysis of seven EU countries so far (Germany, France, Austria, Belgium, the Netherlands, UK and Spain); ERAWATCH and NETWATCH containing information on national programmes and sometimes budgets; own expertise and web-based search.

\(^{29}\) France, Germany, Sweden, Czech Republic, the Netherlands, Romania, Spain, UK, Austria, Belgium, Denmark, Finland and Italy.
an underestimation, the very limited role of public R&D spending becomes obvious. This

certainly applies to the overall investments where the share of public spending remains below
3% of the total, but also to the parts of investments that support research into technologies
aiming at reducing the GHG emissions of vehicles.

Table 2: R&D investments in road vehicle technologies (2008), rounded estimates

<table>
<thead>
<tr>
<th>Technology</th>
<th>Corporate R&amp;D investment, EU-based companies (€m)</th>
<th>Public EU FP7 (€m, avg. per year)</th>
<th>Public MS R&amp;D (€m)</th>
<th>Total R&amp;D investment (€m)</th>
<th>Share of public R&amp;D in road vehicle technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D in road vehicle technologies</td>
<td>31000</td>
<td>150</td>
<td>650</td>
<td>31800</td>
<td>2.5%</td>
</tr>
<tr>
<td>R&amp;D in technologies for reducing GHG &amp; air pollutant emissions</td>
<td>13400</td>
<td>n.a.</td>
<td>n.a.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R&amp;D in technologies for reducing GHG emissions</td>
<td>10000-11000</td>
<td>60</td>
<td>210</td>
<td>10270-11270</td>
<td>2.4-2.6%</td>
</tr>
<tr>
<td>Conventional engines</td>
<td>5000-6000</td>
<td>n.a.</td>
<td>80-125</td>
<td>5080-6125</td>
<td>ca. 2%</td>
</tr>
<tr>
<td>Electric vehicles (incl. hybrids)</td>
<td>1300-1600</td>
<td>20</td>
<td>60-100</td>
<td>1380-1720</td>
<td>5-8.5%</td>
</tr>
<tr>
<td>Fuel cells (&amp; H2 production)</td>
<td>300-400 (100)</td>
<td>65 (15)</td>
<td>135 (45)</td>
<td>500-600 (160)</td>
<td>33-40%</td>
</tr>
<tr>
<td>Transport biofuels</td>
<td>ca. 270</td>
<td>55</td>
<td>65</td>
<td>390</td>
<td>31%</td>
</tr>
</tbody>
</table>

Source: IPTS

Notes: Due to important data gaps in basic data and the subsequent need to approximate missing information in order to derive results at the EU-level, the results shown are associated with important uncertainties. The estimation of corporate R&D investments bases on the analysis of 50 companies. For public R&D investments on FCVs, biofuels, EV and conventional engines, data are taken from the IEA RD&D statistics (with gap-filling applied). The public R&D investments in road vehicle technologies and the parts directed towards GHG emission reduction technologies is based on a combination of other sources (e.g. EAGAR project and national sources). Data have been available for 13 Member States only. The figures for FP7 are annualised over the duration of the programme; they include funding of the HFC JTI and the European Green Cars Initiative.

With regard to individual technologies, public R&D investments follow a ranking opposite to that of corporate investments. This can be explained by industrial research efforts generally preferring relatively mature technologies, and public efforts concentrating on less mature technologies and research of more basic nature. This fact underlines the more elevated importance of public research in fuel-cell related research compared to e.g. electric vehicles.

In general, however, the limited share of public R&D efforts in the road transport sector becomes evident, in particular when compared to (non-nuclear) low-carbon energy technologies with the share of public R&D spending being in the order of 20-45%.

Key message 4: Public R&D funds are very low when compared to the industrial R&D efforts in the automotive sector. Public research efforts may have therefore a limited role in the innovation of the sector in general. They are more suited and needed to complement R&D on less mature technologies, given that industrial research efforts tend to be directed towards technologies that deliver results rather on the short- or medium-term. Moreover, public research is well positioned to address cross-modal R&D, which involves several sectors at the same time.
5.2 Stimulating innovation in the automotive sector

Innovation efforts are often limited due to risk aversion, freerider concerns and the need for making short-term profits. Three relevant distinct flows of spillovers can be distinguished: Firstly, spillovers occur because the workings of the market for an innovative good create benefits for consumers and non-innovating firms ("market spillovers"). Secondly, spillovers occur because knowledge created by one firm is typically not contained within that firm, and thereby creates value for other firms and other firms' customers ("knowledge spillovers"). Thirdly, because the performance of interrelated technologies may depend on each other, each firm improving one of these related technologies creates economic benefits for other firms and their customers ("network spillovers").

The enforcement of private property rights through e.g. patenting is a way of limiting spillovers for the innovator. Nevertheless, a balance between incentives for innovation and competition needs to be found; the modern view reported in ITF (2010) argues that even though innovators need to be rewarded, a too strong protection can easily carry high costs through second-order effects.

While an innovation-friendly framework is beneficial for all sectors, the question arises whether there is a particular need to stimulate innovation in the automotive sector. The previous assessment (section 2) demonstrates that the automotive industry is a research intensive sector, which is backed by theoretical considerations. Unlike for the energy sector with its low corporate R&D efforts, the need for stimulating additional innovation in the automotive sector is therefore less pronounced.

Key message 5: Public intervention can stimulate additional and/or steer existing research efforts. The elevated industrial R&D investments of the sector suggest that stimulating additional R&D may be less needed than ensuring that present R&D investments contribute to the policy targets.

5.3 Steering research by regulation

Past experience shows that environmental innovation within the automotive industry has largely been in response to government regulation of industry (for example, Gerard and Lave, 2005; Dyerson and Pilkington, 2000; Weber and Hoogma, 1998). The impact of government intervention for environmental purposes was first evident in the US when California initiated legislation for automobile emissions in 1960, and subsequently the 1970 federal Clean Air Act was introduced. This demanded 90% emissions reductions from new automobiles over a four- to five-year period (Gerard and Lave, 2005). In response, GM and Ford invested heavily in R&D and equipment installation for technologies to reduce emissions of hydrocarbons, carbon monoxide and nitrogen oxides, eventually leading to production of the automotive catalytic converter in 1975 and the three-way catalyst in 1981. Important in this respect, however, is regulator credibility, without which environmental legislation is unlikely to be effective. For example, Gerard and Lave (2005) suggest that Chrysler may not have responded to the Clean Air Act by investing in R&D due to their belief that regulators would not enforce the Act (since Congress had constrained the Environmental Protection Agency’s administrative options). On the other hand, the company’s financial distress was also a probable factor in its lack of investment in emissions control technologies.
More recently, in 1990, the California Air Resources Board (CARB) announced its Zero Emission Vehicle (ZEV) programme which would require automobile manufacturers to produce and sell an increasing proportion of zero emission vehicles from their new car sales – 3 per cent in 1998, rising to 10 per cent by 2003. After fierce lobbying from auto firms, this legislation was postponed to 2005 and revised to include a new category (the partial-ZEV) which would include fuel-efficient internal combustion engines (ICEs), for example, hybrids, methanol/gasoline fuel cell vehicles (FCVs), and natural gas vehicles (Hekkert and van den Hoed, 2006). Similar mandates are in force elsewhere (e.g., Switzerland). This has prompted major public and private investment in electric and subsequently hybrid and fuel cell vehicles, not only amongst US car producers but also by Japanese and European firms (Dyerson and Pilkington, 2000). Other US policies, such as the 1992 Energy Policy Act and the current Bioenergy Program, which promote bio-ethanol production and use have encouraged major manufacturers, such as Toyota, to invest in flexible-fuel vehicles (Toyota, 2006).

Also in Japan, government policy has similarly stimulated environmental innovation within the automotive sector. As part of its programme to develop and promote clean vehicle technologies, the MITI has created technological ‘visions’ through collective foresight exercises, established intercompany knowledge networks, sponsored R&D, leasing and purchasing incentive programmes, subsidies for electric vehicle manufacturers, public procurement (e.g., electric Toyota ‘Rav4’s sold to some Japanese authorities) and facilitated market entry through legislation and standards (Åhman, 2006). This programme, along with the CARB zero-emission vehicles mandate, has been a key determinant of Toyota’s investment in, and ultimate commercial success with, hybrid electric-ICE vehicles (Åhman, 2006).

New EU legislation Regulation (EC 443/2009) setting CO₂ emissions limits on cars from 2012 130g CO₂/km requires rapid action from manufacturers and together with the California ZEV standards, adapted in 2009 to allow for hybrids (CEP-ARB, 2010) has provided a decisive push towards the development of battery electric hybrids by all the auto majors. Furthermore, US policy has now cut hydrogen development funding in favour of electric vehicles. New (2010) US subsidies for electric vehicle R&D (Nissan Leaf introduction in US (Auto Motor und Sport, 2009) have e.g. convinced Renault-Nissan-NEC to introduce their hybrid in the US before the EU.

Eventually, by setting the right signals, policy can contribute to the creation of a lead-market that brings long-term benefits to EU-based industry. Lead-markets are countries that first adopt a globally dominant innovation design (Beise and Rennings, 2005). Companies forming the lead market are at the forefront of the diffusion of the innovative technology/product and are the first to experience the benefits of 'technology learning'. They can also register patents and form the market so as to protect competitors to enter. A first-mover company is thus better positioned than his competitors when demand for 'his' technology increases and gains world market shares.

**Key message 6: Long term binding targets and regulation can steer innovation in the desired direction. This path has been followed by the EU by setting binding limits for the CO₂ emissions of the new vehicle fleet by 2015 and 2020. For companies to better adjust the direction of their strategic long-term research efforts and to bring it in line with EU climate policy, clear and reliable targets beyond 2020 are desirable.**
In addition to guiding innovation towards a certain goal, public research policies also aim at 'keeping all options open'. As mentioned above, industry would in general tend to favour research in options that are more mature. This can create a certain technology lock-in or path-dependency in one innovative technology at the expense of another, which becomes even more important when the competing technologies require different infrastructures to be built up. A lock-in effect is not restricted to technologies only but also comprises the related complex scientific and economic framework (e.g. Unruh, 2000), the so-called 'technological regime' (Kemp et al., 2000). One of the aims of policy is to counteract these lock-in effects.

Even though this is of less importance in automotive sector than in the energy sector due to the more limited number of competing low-carbon technologies in the first, policy needs to make sure that the recent boom in (research on) electric vehicles does not happen at the expense of continuous efforts in developing fuel cell vehicles.

Moreover, despite the automotive industry being the key actor for innovation in road vehicle technologies, the surrounding factors for a technology to become a success need to be kept in mind. Hence, innovation needs to consider the whole chain of vehicles, fuels, tanking/charging infrastructure and consumer preferences instead of focusing on the vehicle engine technologies alone. This involves a large variety of diverse actors, each of which may follow their own research agenda. In order for all relevant actors to work towards an agreed timeline for the development of a certain technology with respect to fuel supply (production and distribution infrastructure) and engine technologies, the elaboration of joint technology roadmaps may be a suitable tool.

A number of initiatives are already following this path. The Hydrogen and Fuel Cell Joint Technology Initiative (HFC JTI) is a public-private partnership launched in 2008 with the goal to accelerate the market entry of fuel cell and hydrogen technologies for applications in transport, stationary and portable power. It has been established in May 2008 in order to speed-up the development of fuel cell and hydrogen technologies so that to bring them on the market by 2020. The HFC JTI will run until 2017 with a minimum budget of €940 million (€470 million from both the European Community and the private sector).

The European Biofuels Technology Platform, a public-private partnership that was initiated in 2006, elaborated a Strategic Research Agenda that identified key RD&D needs on bioenergy for the next decades. It has contributed to formulate industrial objectives on bioenergy in the context of the implementation of the European Strategic Energy Technology Plan30. On this basis, the European Industrial Initiative on Bioenergy is currently being shaped.

The European Green Cars Initiative (EGCI) is one of the three Public Private Partnerships of the European Economic Recovery Plan. Its objective is to 'facilitate research on a broad range of technologies to achieve a breakthrough in the use of renewable and non-polluting energy sources for road transport'. The initiative includes R&D, mainly through FP7.

---

30 SEC(2009)1295
Key message 7: Innovation in road transport involves the whole chain of fuel production and supply infrastructure and engine technologies. The development of technology roadmaps could help car manufacturers and fuel suppliers in the coordination to agree on a common trajectory for the development of a technology. Moreover, technology roadmaps may be a tool to ensure that also long-term solutions are being kept open. Several steps in this direction have been taken at the EU level, such as the HFC JTI, the European Industrial Initiative Bioenergy and the European Green Cars Initiative.

5.4 Creating market demand

Innovation depends on a wide variety of factors throughout all phases of the innovation chain, i.e. the scientific R&D and market introduction of new technologies. Technology push-policies such as additional R&D expenditure can increase the incentive for technological innovation. On the other hand, a demand for a new product needs to be created by market-pull policies. The demand is determined by the relative competitiveness of the new low-carbon technology compared to its mature, high-emission alternative.

![Figure 7: Activities for spanning the innovation chain](source: Grubb, 2004)

This can be realised both by dedicated technology-specific pull-instruments (such as purchase subsidies, (fuel) tax incentives or preferential taxation of efficient/innovative business cars) and by internalising the external costs (either directly through pricing of e.g. carbon dioxide or through the setting of standards). Another way of creating a niche market demand may be through public procurement that forms a considerable share of total demand in Europe (Edler, 2006). PriceWaterhouseCoopers (2005) estimates that at the EU-25 level, public bodies purchase around 110000 passenger cars, 110000 LDVs, 35000 HDVs and 17000 buses. To this end, directive 2009/33/EC on the promotion of clean and energy efficient road transport vehicles requires public authorities to take into account the energy and environmental impacts of vehicles over their lifetime when purchasing new vehicles.

Key message 8: Public involvement helps new technologies to enter the market through dedicated market-pull mechanism, including differentiated taxation and public procurement. This complements the technology-push policies focusing on the R&D.
6 Conclusions

The EU-based automotive industry is the largest private research investor in the EU with a volume of R&D investments of more than €30 billion in 2008. About one third of these (€10-11 billion) are directed towards research efforts in technologies that reduce the GHG emissions of vehicles. With regard to road vehicle engine technologies, great importance is given to R&D on efficiency improvements of conventional engines and to electric vehicles, with the steeply rising patent applications for the latter indicating a rapidly growing activity in recent years. At the same time, R&D efforts in other long-term options such as fuel-cell vehicles remain lower. Public R&D investments in the automotive sector are very low compared to industry's efforts, in particular when compared to the energy sector.

The high (and increasing) R&D effort of both automotive manufacturers and suppliers indicate that the sector is research-intensive, an evidence that seems backed by theoretical considerations. Hence, public intervention is less needed to stimulate additional research efforts but rather to direct existing research efforts so as to make sure that also promising long-term technologies are being developed. This need is confirmed by recent research, which indicates that in particular for the medium- and long-term time horizon, significant further reductions of transport-related GHG emissions are needed beyond those that can be achieved with current technologies and policies.

Past experience proves the impact of the prescription of environmental standards via specific regulation on directing innovation in vehicle technology. Creating appropriate framework conditions for steering the automotive sector's research efforts is therefore of high relevance and impact. The EU's CO₂ specific emission limits set for 2015 and 2020 are a crucial step, but ambitious, realistic and credible targets beyond 2020 are required in order for the automotive sector to better focus their long-term R&D strategy and to bring it in line with the EU climate policy targets.

The elaboration of technology roadmaps can be considered as another valuable R&D policy orienting tool, allowing stakeholders from different sectors to converge towards agreed trajectories of technology development, and therefore complementing efforts in vehicle technologies with those on the side of fuel production and distribution infrastructure. Several steps in this direction have been taken at the EU level, such as the HFC JTI, the European Industrial Initiative Bioenergy and the European Green Cars Initiative.

Public R&D investments can also influence the direction of research in this sector to some extent, even though its role is limited in the automotive sector as a whole. The role of public research efforts are suited and needed to complement the development of long-term options that are considered less mature, as industrial research efforts tend to be biased towards technologies that deliver short- and medium-term results (e.g. efficiency improvements or electric vehicles). Moreover, public research is well positioned to address cross-modal R&D.

---

31 This figure rises to around €13 billion when also including research into measures that reduce emissions of regulated air pollutants.
Finally, since the successful market introduction of technologies necessitates a combination of (R&D) technology-push and market-pull mechanisms, public intervention needs to consider the creation of incentives that raises demand for new products, e.g. by using its market power via public procurement as also requested by directive EC/2009/33.

Note that the above analysis applies to the automotive sector, only. The role of public R&D in other transportation modes is significantly higher than in the automotive sector, being in the order of around 20% or more of the total investments. At the same time, these sectors invest a lower share of their R&D efforts in technologies to reduce GHG emissions. One may thus argue that the need for and the potential of public R&D funds in steering research towards low-carbon alternatives is higher than for the automotive sector.
7 References


List of acronyms

ACEA   European Automobile Manufacturers' Association
BEV    Battery Electric Vehicle
bn     billion
CARB   California Air Resources Board
EEA    European Environment Agency
EU or EU-27 European Union
EV     Electric Vehicle
FC     Fuel Cell
FCV    Fuel Cell Vehicle
FP7    7th Research Framework Programme
GBAORD Government Budget Appropriations or Outlays on R&D
GHG    Greenhouse gas
H2/FC  Hydrogen and Fuel Cells
HDV    Heavy Duty Vehicle
HEV    Hybrid Electric Vehicle
ICB    Industry Classification Benchmark
ICE    Internal Combustion Engine
IEA    International Energy Agency
ITS    Intelligent Transport Systems
JTI    Joint Technology Initiative
LDV    Light Duty Vehicle
MITI   Ministry of International Trade and Industry (Japan) – Renamed Ministry of Economy Trade and Industry (METI) in 2001
PHEV   Plug-in Hybrid Electric Vehicle
RD&D   Research, Development and Demonstration
R&D    Research and Development
SETIS  Strategic Energy Technology Plan Information System
SET-Plan European Strategic Energy Technology Plan
ZEV    Zero Emission Vehicle
Abstract

The automotive sector is the largest industrial R&D investor in the EU. The present note assesses which parts of the sector's research efforts are dedicated towards the development of low-carbon vehicle technologies. The results indicate that relevant companies invest significant amounts in the development of more efficient conventional engine technologies and in electric vehicles, while fuel-cell vehicles have become of lower interest. The note suggests that the role of the public sector should focus on guiding research of this sector so as to bring it in line with the EU climate policy targets. To this end, setting long-term targets and regulation are considered an important tool together with the creation of market demand measures.
The mission of the Joint Research Centre is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of European Union policies. As a service of the European Commission, the Joint Research Centre functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.