EU Transport GHG: Routes to 2050?

An overview of the factors that limit new technology and concepts in the transport sector (Task 9 Report IV)

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Table of contents

Executive Summary iv
1 Introduction 1
1.1 Topic of this paper 1
1.2 The contribution of transport to GHG emissions 1
1.3 Background to project and its objectives 4
1.4 Background and purpose of the paper 5
1.5 Structure of the paper 5
2 Review of evidence of turnover of the fleet and development of infrastructure 6
2.1 Introduction 6
2.2 Average and maximum vehicle lifetime 6
2.3 Retrofitting possibilities 7
2.4 Evolution of vehicle lifetimes 7
2.5 Time required for vehicle model planning and design 9
2.6 Time required for changes in infrastructure 12
2.7 GHG emission reductions – issues to consider 13
2.8 Potential implications for GHG emissions 17
3 Barriers and Opportunities 18
3.1 Introduction 18
3.2 Research and design of new technologies 18
3.3 Barriers and opportunities associated with the introduction of these technologies.... 19
4 Case Studies 24
5 Conclusions 29
Annex 1 30

Executive Summary

In recent years GHG emissions from the transport sector in Europe have continued to increase whist the GHG emissions from other sectors have stabilised or begun to fall. Unless action is taken, transport GHG emissions alone will exceed an 80% reduction for all sectors or make up the vast majority of a 60% reduction target. This illustrates the scale of the challenge facing the transport sector given that it is unlikely that GHG emissions from other sectors will be eliminated entirely. In this context the overarching aim of the project is to provide guidance and evidence on the broader policy framework for controlling greenhouse gas (GHG) emissions from the transport sector.

The project has collated the relevant evidence for options to reduce transport's GHG emissions. These options include the use of new, lower carbon technologies across all modes – cars, trains, ships and planes. The main objective of this Task 9 Report IV is to examine the conditions, which will affect the uptake of these technologies. This includes timescales for vehicle lifetimes and for the introduction of new infrastructure. Barriers and opportunities for new technologies are also considered.

The paper suggests the following outcomes:

- Action needs to be taken now if full emission reduction from aviation, rail and shipping is to be achieved by 2050. This is a result of the long lifetimes for these modes, as well as the time required to design and build new technologies. Full use must therefore be made of retrofitting opportunities for these modes.

- For all modes, 'unexpected impacts' which reduce the GHG savings need to be fully understood and if possible reduced. This could include new technologies resulting in shorter lifetimes for vehicles or vehicle components.

- Infrastructure for new fuels and to facilitate modal shift will also take time to implement. Land use planning will be a key consideration here.

- The study identified a number of barriers and opportunities to the implementation of new technologies including social and attitudinal and regulatory.

- Case studies suggest that the take up of new technologies has previously been achieved.

1 Introduction

1.1 Topic of this paper

This paper is one of a series of papers on GHG reduction options for transport drafted under the *EU Transport GHG: Routes to 2050?* Project. These papers review the options – technical and non-technical – that could contribute to reducing transport's GHG emissions, both up to 2020 and in the period from 2020 to 2050. This paper focuses on the limitations to reducing GHG emissions from the transport sector as a result of time lags arising from:

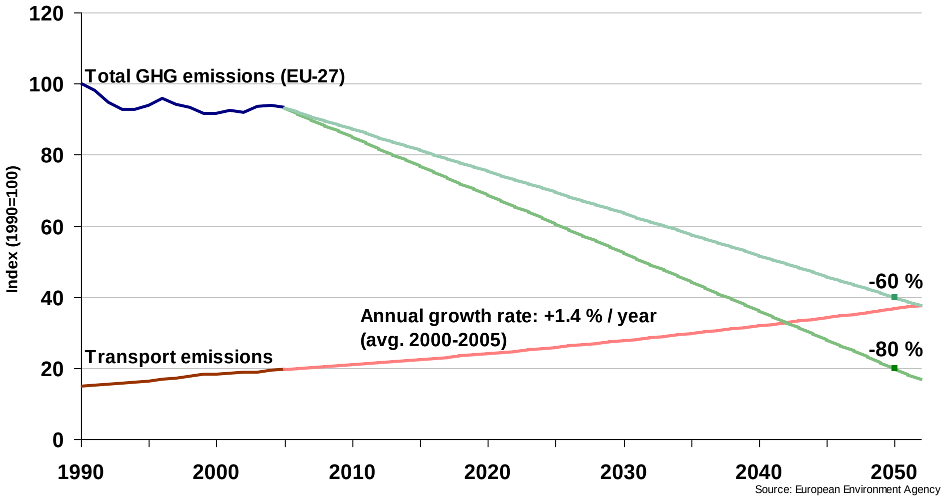
- Vehicle lifetimes;
- Technological deployment; and
- Infrastructure construction times.

Quantitative outcomes, where possible are identified, and will be used in the modelling of different emission reduction scenarios. Barriers and opportunities for new technologies are also considered. . The paper aims to provide a high-level summary of the evidence based on existing.

1.2 The contribution of transport to GHG emissions

The EU-27's greenhouse gas (GHG) emissions from transport have been increasing and are projected to continue to do so. The rate of growth of transport's GHG emissions has the potential to undermine the EU's efforts to meet potential, long-term GHG emission reduction targets if no action is taken to reduce these emissions. This is illustrated in Figure 1 (provided by the EEA), which shows the potential reductions that would be required by the EU if economy-wide emissions reductions targets for 2050 of either 60% or 80% (compared to 1990 levels) were agreed and if GHG emissions from transport continued to increase at their recent rate of growth. The figure is simplistic in that it assumes linear reductions and increases. However it shows that unless action is taken, by 2050 transport GHG emissions alone would exceed an 80% reduction target for all sectors or make up the vast majority of a 60% reduction target. This illustrates the scale of the challenge facing the transport sector given that it is unlikely that GHG emissions from other sectors will be eliminated entirely.

Figure 1: EU overall emissions trajectories against transport emissions (indexed)[1]



Source: European Environment Agency

The extent of the recent growth in transport emissions is reinforced by Figure 2, which presents a sectoral split of trends in CO_2 emissions over recent years. Whilst the CO_2 emissions from other

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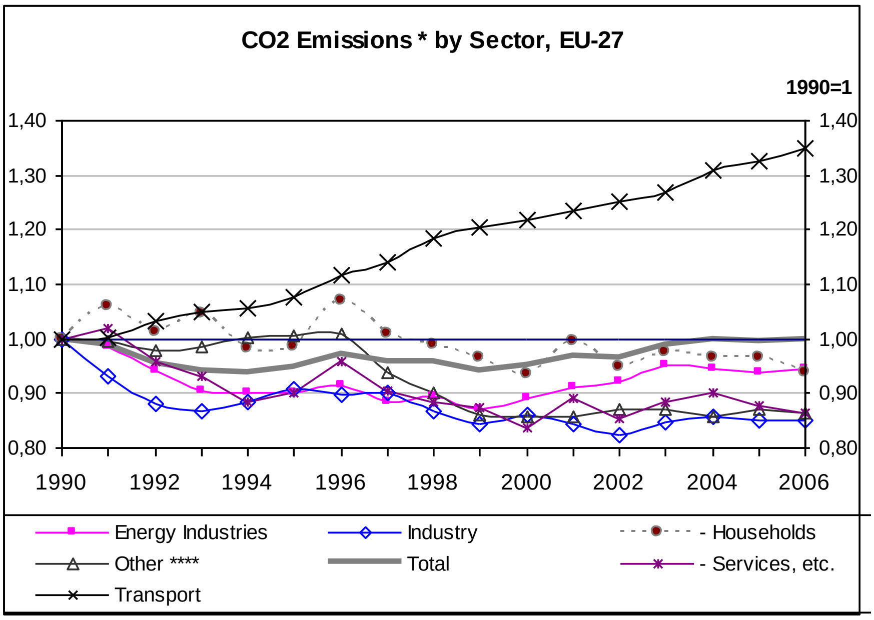
[1] Graph supplied by Peder Jensen, EEA

sectors have levelled out or have begun to decrease, transport's CO_2 emissions have risen steadily since 1990. It should be noted that whilst Figure 2 is presented in terms of CO_2 emissions, very similar trends are evident for GHG emissions (in terms of CO_2 equivalent) since CO_2 emissions represent 98% of transport's GHG emissions.

Figure 2: Carbon dioxide emissions by sector EU-27 (indexed)[2]



Notes:

i) The figures include international bunker fuels (where relevant), but exclude land use, land use change and forestry

ii) The figures for transport include bunker fuels (international traffic departing from the EU), pipeline activities and ground activities in airports and ports

iii) "Other" emissions include solvent use, fugitive emissions, waste and agriculture

The vast majority of European transport's GHG emissions are produced by road transport, as illustrated in Figure 3, while international shipping and international aviation are other significant contributors.

Recent trends in CO_2 emissions from transport are also expected to continue, as can be seen from Table 1 below. Between 2000 and 2050, the JRC (2008) estimates that GHG emissions from domestic transport in the EU-27 will increase by 24%, during which time emissions from road transport are projected to increase by 19% and those from domestic aviation by 45%. It is important to note that these projections do not include emissions from international aviation and maritime transport, which are also expected to increase due to the growth in world trade and tourism.

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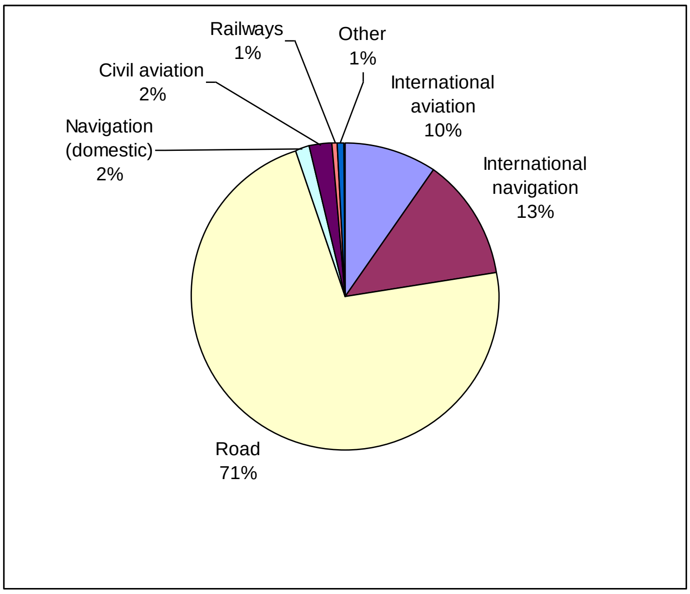
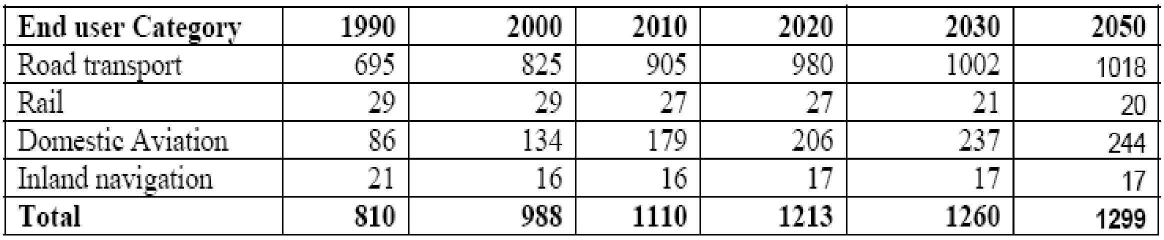
[2] Graph based on figures in DG TREN (2008) *EU energy and transport in figures 2007-2008: Statistical Pocketbook* Luxembourg, Office for Official Publications of the European Communities.

Figure 3: Greenhouse gases emissions by transport mode (EU-27; 2005)[3]



Note: The figures include international bunker fuels for aviation and navigation (domestic and international)

Table 1: CO_2 emissions projection for 2050 by end-users in the EU-27, in Millions tonnes of Carbon[4]



End user Category	**1990**	**2000**	**2010**	**2020**	**2030**	**2050**
Road transport	695	825	905	980	1002	1018
Rail	29	29	27	27	21	20
Domestic Aviation	86	134	179	206	237	244
Inland navigation	21	16	16	17	17	17
Total	**810**	**988**	**1110**	**1213**	**1260**	**1299**

Figures from the EEA (2008), illustrate the recent growth in GHG emissions from international aviation, as they estimate that these increased in the EU by 90% (60 Mt CO_2e) between 1990 and 2005; international aviation emissions will thus become an ever more significant contributor to transport's GHG emissions if current trends continue. Furthermore, the IPCC has estimated that the total impact of aviation on climate change is currently at least twice as high as that from CO_2 emissions alone, notably due to aircrafts' emissions of nitrogen oxides (NO_x) and water vapour in their condensation trails. However, it should be noted that there is significant scientific uncertainty with regard to these estimates, and research is ongoing in this area.

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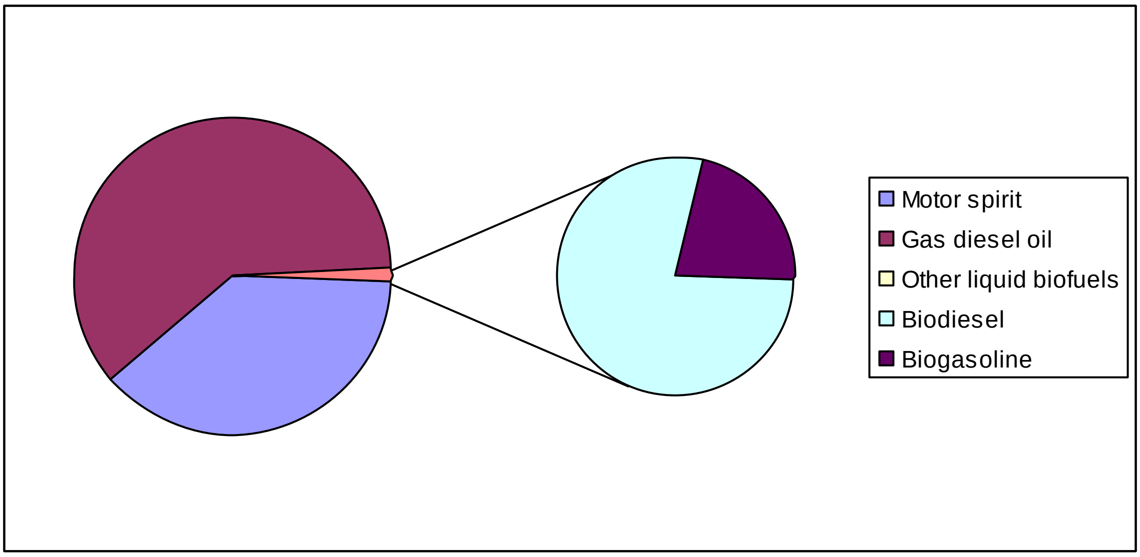
[3] Graph based on figures in EEA (2008) *Climate for a transport change – TERM 2007: Indicators tracking transport and environment in the European Union* EEA Report 1/2008, Luxembourg, Office for Official Publications of the European Communities.

[4] Taken from JRC (2008) *Backcasting approach for sustainable mobility* Luxembourg, EUR 23387/ISSN 1018-5593, Office for Official Publications of the European Communities.

Figure 4: Final transport energy consumption by liquid fuels in EU-27 (2005), ktoe[5]



The principal source of transport's GHG emissions is the combustion of fossil fuels. Currently, petrol (motor spirit), which is mainly used in road transport (e.g. in passenger cars and some light commercial vehicles in some countries), and diesel, which is used by other modes (e.g. heavy duty road vehicles, some railways, inland waterways and maritime vessels) in various forms, are the most common fuels in the transport sector (see Figure 4). Additionally, liquid petroleum gas (LPG) supplies around 2% of the fuels for the European passenger car fuel market (AEGPL, 2009[6]), while the main source of energy for railways in Europe is electricity, neither of which are included in Figure 4. While, alternative fuels are anticipated to play a larger role in providing the transport sector's energy in the future, currently they only contribute 1.1% of the sector's liquid fuel use.

1.3 Background to project and its objectives

The context of the *EU Transport GHG: Routes to 2050* is the Commission's long-term objective for tackling climate change, which entails limiting global warming to 2°C and includes the definition of a strategic target for 2050. The Commission's President Barosso recently underlined the importance of the transport sector in this respect be noting that the next Commission "needs to maintain the momentum towards a low carbon economy, and in particular towards decarbonising our electricity supply and the transport sector"[7]. There are various recent policy measures that are aimed at controlling emissions from the transport sector, but these measures are not part of a broad strategy or overarching goal. Hence, the key objective of this project is to provide guidance and evidence on the broader policy framework for controlling GHG emissions from the transport sector. Hence, the project's objectives are defined as to:

- Begin to consider the long-term transport policy framework in context of need to reduce greenhouse gas (GHG) emissions economy-wide.
- Deal with medium- to longer-term (post 2020; to 2050), i.e. moving beyond recent focus on short-term policy measures.
- Identify what we know about reducing transport's GHG emissions; and what we do not.
- Identify by when we need to take action and what this action should be.

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[5] Graph based on figures in DG TREN (2008), page 206
[6] European LPG Association (2009) *Autogas in Europe, The Sustainable Alternative: An LPG Industry Roadmap,* AEGPL, Brussels. See http://www.aegpl.eu/content/default.asp?PageID=78&DocID=994
[7] http://ec.europa.eu/commission_barroso/president/pdf/press_20090903_EN.pdf

Given the timescales being considered, the project will take a qualitative and, where possible, a quantitative approach. The project has three Parts, as follows:

- Part I ('Review of the available information') has collated the relevant evidence for options to reduce transport's GHG emissions, which was presented in a series of Papers (1 to 5), and is in the process of developing four policy papers (Papers 6 to 9) that outline the evidence for these instruments to stimulate the application and up take of the options.
- Part II ('In depth assessment and creation of framework for policy making') involves bringing the work of Part I together to develop a long-term policy framework for reducing transport's GHG emissions.
- Part III ('Ongoing tasks') covers the stakeholder engagement and the development of additional papers on subjects not covered elsewhere in the project.

As noted under Part III, stakeholder engagement is an important element of the project. The following meetings were held:

- A large stakeholder meeting was held in March 2009 at which the project was introduced to stakeholders.
- A series of stakeholder meetings (or Technical Focus Groups) on the technical and non-technical options for reducing transport's GHG emissions. These were held in July 2009.
- A series of Technical Focus Groups on the policy instruments that could be used to stimulate the application of the options for reducing transport's GHG emissions. These were held in September/October 2009.
- Two additional large stakeholder meetings at which the findings of the project were discussed.

As part of the project a number of papers have been produced, all of which can be found on the project's website, as can all of the presentations from the project's meetings.

1.4 Background and purpose of the paper

This paper "An overview of the factors that limit new technology and concepts in the transport sector" has been drafted under the Part III of the project, Task 9 "Ad hoc papers", here the main objective is to provide the Commission with ad hoc written support/briefings and concise analytical/discussion papers on issues related to the project's core work.

New technology options have been identified in other Papers under this project. The purpose of this paper is to look at the conditions affecting the uptake of these technologies. This includes a review of the lifetime of vehicles, and the time taken to develop new technologies. Barriers and opportunities have also been considered, and case studies provided.

1.5 Structure of the paper

The structure of the paper is as follows:

- **Section 2** covers a review of the average lifetime of vehicles, the turnover of the fleet and the development of infrastructure.

- **Section 3** examines barriers and opportunities for the uptake of new technologies.

- **Section 4** consists of case studies which explore and consider the above themes.

- **Section 5** is the conclusion, summarising key themes as they relate to deployment and impact on greenhouse gas emission reduction.

2 Review of evidence of turnover of the fleet and development of infrastructure

2.1 Introduction

This section considers key issues as they relate to:

- Average lifetimes of current vehicles and retrofitting possibilities
- Evolution of vehicle lifetimes
- Time required for vehicle model planning and design
- Time required for development of infrastructure
- GHG emission reduction – issues to consider and potential implications

An understanding and quantification of these issues is essential to determine how new technologies could be deployed by mode, therefore helping us to understand the plausibility of different options on a 2050 timescale.

2.2 Average and maximum vehicle lifetime

This section first considers the current average and maximum vehicle lifetime of different modes, including cars, light commercial vehicles (LCVs), Heavy Goods Vehicles (HGVs,) rail, inland waterway vessels, ships and aircraft.

In the majority of cases, vehicles are scrapped at the end of their lifetime, but in some (such as in the aviation industry), they cease to be used in the EU and are exported for use in other countries.

In determining these lifetimes it should be noted that peer reviewed, up to date literature, on vehicle lifetimes was relatively limited. This section therefore draws conclusions based on two sources types:

- The literature available; and
- Assumptions used in established forecasting models such as the UK MARKAL energy model, TIMES and TREMOVE

The outcomes of this analysis are shown in Table 2. An explanation of the sources used is provided in Annex 1 for each of the transport modes.

Table 2: Average vehicle lifetime by different mode

Mode	Average and maximum vehicle lifetimes (years)
Cars (Gasoline)	12[8] potentially up to ~ 20
Cars (Diesel)	12 - 15[9] potentially up to ~ 20[8]
LCVs	10 ~ potentially up to~ 20[10]
HGVs	7 ~ potentially up to ~ 25[11]
Railway engines and carriages	35[12]
Inland water vessels	No information available
Ships	28[13]
Airplanes	30[14]
Buses	12[15] potentially up to ~ 15

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[8] MARKAL suggests 12. TREMOVE base case suggests that in 2010 98% would be 20 years and under 82% 12 years and under.

[9] Source: IEA, Passenger light duty vehicles – Marginal abatement costs in WEO2009. http://www.iea.org/weo/docs/weo2009/PLDV_Methodology_&_Sensitivity.pdf

[10] MARKAL suggests 10. TREMOVE base case suggests that for light duty vehicles in 2010 90% of vehicles would be 20 years and under, 54% would be 10 years and under.

[11] MARKAL suggests 7 for HGV. TREMOVE base case suggests that in 2010 98% of heavy duty trucks would be 25 years and under. Around 40 to 45% would be 7 years and under. Note that the figures are for different types of heavy vehicles.

[12] See Annex and note TREMOVE base case suggests that 90% of passenger trains are under 35 years old and 91% of freight trains.

[13] The lifespan of ships varies depending on the size, material and function of the vessel. Most ocean-going cargo ships have a life expectancy of between 20 and 30 yrs. A sailboat made of plywood or fiberglass can last between 30 and 40 years. Solid wooden ships can last much longer than this but require regular maintenance. Steel-hulled yachts that are carefully maintained can have a lifespan of over 100 yrs. See Annex.

[14] See Annex also note http://www.airfleets.net/ageflotte/fleet-age.htm suggests that airlines fleets used in Europe would have a much lower average age.

It is clear that larger modes – ships, planes and trains - have longer lifetimes than road vehicles.

It should also be noted that average numbers hide a wide variation and are UK focussed. TREMOVE numbers, while illustrating maximum rather than average lifetimes help illustrate the potential range.

2.3 Retrofitting possibilities

Retrofitting possibilities could help reduce the intensity of GHG emissions during the lifetime of the vehicle. Possible retrofit options and the GHG emission reduction associated with them are shown in Table 3. Given the long lifetimes of ships, planes and rail these retrofitting measures could make an important contribution to GHG emission reduction. .

Table 3: GHG Emission Retrofit Options

Mode	Retrofitting options
Ships [16]	Hull retrofitting e.g. adding grids or optimizing the flow of tranverse thrusters openings[17] could save 1 to 5% and are broadly applicable. Reduction of friction resistance using modern hull coating could save up to 6%[18] Propeller and propulsion system upgrades e.g. application of special tip shapes to the propeller can lead[18] to a maximum fuel saving of 4% on ship level. Main engine – savings of ~ 2% could be achieved
Aviation	For a very limited number of aircraft, there is a possibility of fitting modern, quiet, fuel efficient engines[60] APU's could be replaced with fuel cells[19] Aerodynamics can be improved using winglets, wingtip devices, riblets and the application of surface coatings to reduce skin friction drag. Winglets can offer savings of 4% to 6%. Riblets could offer savings of 2%. Aeroplane interiors can be reconfigured, lighter seats can be used
Rail	Trains can be retrofitted with LED lighting to reduce their energy consumption. Reductions in energy use associated with air conditioning. It is suggested that a 4% saving in electricity from heating and cooling could be achieved[20].
Inland waterway	Diesel Oxidation Catalysts (DOCs)[21] can be installed on inland waterway vessels.

2.4 Evolution of vehicle lifetimes

In terms of likely evolution of vehicle lifetimes and the average age of the vehicle there are a number of issues to consider. These include:

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[15] Transport Travel Research (2008) Report for Passenger Transport Executive Group - Scenarios and Opportunities for Reducing GHG / Pollutants from Bus Fleets in PTEs / SPT. TREMOVE basecase for 2010 suggests that 86% of vehicles would be 12 years and under and that 97% of vehicles would be 15 years and under

[16] IMO (2009) prepared by Marintek, Norway, CE Delft, the Netherlands, Dalian Maritime University, China, Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Germany, DNV, Norway, Energy and Environmental Research Associates (EERA), USA, Lloyd's Register – Fairplay Research, Sweden, Manchester Metropolitan University, UK, Mokpo National Maritime University (MNMU), Korea , National Maritime Research Institute (NMRI), Japan, Ocean Policy Research Foundation (OPRF), Japan

[17] Hazeldine, Pridmore, van Essen and Hulskotte (2009) *Technical Options to reduce GHG for non-Road Transport Modes.* Paper produced as part of contract ENV.C.3/SER/2008/0053 between European Commission Directorate-General Environment and AEA Technology plc; see website www.eutransportghg2050.eu

[18] Wärtsilä (2008) Boosting energy efficiency, Energy Efficiency Catalogue, September 2008.

[19] Massachusetts Institute of Technology (2008) Evaluating Potential Measures to Reduce Aviation Fuel Consumption and Carbon Emissions http://web.mit.edu/airlines/industry_outreach/board_meeting_presentation_files/meeting-nov-2008/Bonnefoy%20Aviation%20Fuel%20and%20Emissions.pdf

[20] Christian Peckam, Interfleet Technology (2007) *Improving the Efficiency of Traction Energy Use*. Rail Safety and Standards Board.

[21] http://www.dieselprogress.com/prod_detail.asp?pick=2342&from=P

- The lifetime of new technologies
- The speed at which technologies penetrate the market; and
- The impact of changed patterns of vehicle ownership
- The impact of policy measures

These issues are considered in turn below.

2.4.1 The lifetime of new technologies

The lifetime of new technologies may differ from that of current vehicles. For example, for electric vehicles there is the potential for the driving performance to diminish over the lifetime of the vehicle quite significantly. A brand new plug-in vehicle that has a 60 mile range may only travel 40 miles by the defined "end of life". All vehicles show degraded performance as they age, but the symptoms of age for an electric car may be more pronounced and take some time for customers to accept than other modes. This is likely to present issues for the success of the technology – if lifetime is in unacceptable, it is unlikely that the technology will be successful. However, this issue with reduced lifetime for electric vehicles can be partially addressed through the leasing of batteries rather than owning them, ensuring that the performance of electric vehicles is not degraded as quickly as they might have otherwise. Consequently, if electric vehicles have a significant market share in the future, there could be an impact on the lifetime of fleets.

Reductions in the lifetime of new technologies for planes, rail and shipping is likely to be less of an issue given the high costs associated with these modes mean that a key consideration is the lifetime of the vehicle assets.

2.4.2 The speed at which new technologies penetrate the market

Vehicle lifetimes can be influenced by the development of new transport technologies. The speed at which these technologies penetrate the market is therefore a factor in determining the likely evolution of vehicle and fleet timescales. Penetration also strongly depends on the often 'perceived' added value of the product.

Estimates based on the share of vehicles complying with the various legislation classes suggest that it takes at least 10 years for a new technology to penetrate the vehicle fleet in the EU, but that this penetration is slightly quicker for diesel than for petrol cars. The European Environment Agency (EEA) has used the share of passenger cars fitted with catalytic converters as a proxy-indicator for the penetration of new technology into the market. For passenger cars, it has taken more than 10 years to reach a 72% penetration of this new technology (EEA, 2009[22]). However, it should be noted that the use of catalytic converters was required through the introduction of stringent vehicle emissions legislation (a mandatory measure) and therefore cannot necessarily be indicative of technology penetration as a voluntary measure.

In terms of others modes, the proportion of trucks, buses, coaches and aircrafts that comply with the latest and most stringent emission standards is lower than for cars, although trucks often have shorter lifetimes.

For aviation, rail and shipping, a key consideration is the lifetime of vehicle assets. Operators or vehicle owners (if they are not one and the same) are keen to generate as much return on their investment in the vehicles as possible. Therefore, unless there is a very strong business case for replacing the vehicles or retrofitting new technologies they are likely to continue operating their existing fleet. With lifetimes of planes, trains and ships are at around 30 years, the time taken for technologies to fully penetrate the market will be significant. However it is worth noting the relatively young age of aircraft which operate within Europe which suggests that for certain operators turnover

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[22] EEA (2009) Proportion of the vehicle fleet meeting certain emission standards. European Environment Agency. http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20080704103528/IAssessment1225463928210/view_content

may be higher than one would be expect[14]. This may be due to alternative ownership patterns such as leasing.

2.4.3 Changed patterns of vehicle ownership

Since 1990, the average age of passenger cars in the EU has increased. This trend is partly explained by the fact that households purchase new cars but retain the previous, older cars (there has been an increase in the number of cars per household). This may also extend the lifetime of older vehicles as they are not being used as extensively as they might have been in a single car household.

One further aspect to consider is that vehicles that drive many kilometres may not last as long as vehicles which drive less km.

Limited information could be found on the export of 'old' planes from the EU to other countries, but increase in these patterns of use could have important implications in terms of GHG emissions.

2.4.4 Impact of policy measures

There are policy measures that can impact on the lifetime of vehicles and their evolutionary course. The adoption of import bans on certain vehicles, financial incentives and car scrappage schemes can decrease the average age of vehicles. In the 1990s, several EU Member States introduced scrappage schemes to improve the environmental performance of their car fleet including Greece, Denmark, Spain, France, Ireland, Italy and Portugal[23]. Slovenia introduced a ban on second-hand vehicles without a catalytic converter and on cars older than three years[24]. Other policy measures that reduce the attractiveness of high GHG emitting vehicles could bring forward scrappage times.

However, results suggest that scrappage schemes will only have net benefits if future vehicles have emission rates that are substantially better and if at the same time, the environmental impact of vehicle construction and dismantling processes is reduced[23]. For example, if CO_2 emissions per km for a new car decrease by 1.5% per year, and manufacturing is responsible for 15% of lifecycle emissions, then scrapping a car when it is 10 years old is probably just about neutral in GHG terms. Any shorter cycle and it would increase GHG. As use emissions decrease, manufacturing emissions will be accountable for a greater overall share and scrappage schemes would be even less advantageous. Recent research by IPTS[25] also suggests that the introduction of scrappage schemes is not clear cut in terms of GHG emission reduction. It suggests that timing of scrappage schemes is important in terms of GHG emission savings. From the research it could be implied that a key time would be when emission savings from new technologies are at a maximum.

Currently (August, 2009) thirteen EU countries have put a fleet renewal programme in place, which includes market incentives and car scrapping schemes. The drive behind the schemes is to soften the impact of the recession and as well as reducing emissions.

There are other mechanisms to facilitate change[23]. These include:
- Changing the structure of annual vehicle taxation.
- Enhancement of inspection and maintenance programmes can render the operation of older cars more costly and will therefore encourage their scrappage or replacement

2.5 Time required for vehicle model planning and design

The time required for vehicle model planning and design are considered in the following sections.

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[23] ECMT, 1999, *Conclusions and recommendations on scrappage schemes and their role in improving the environmental performance of the car fleet*, CEMT/CM(99)26/FINAL, European Conference of Ministers for Transport, June 1999.
[24] http://star.eea.eu.int
[25] Joint Research Centre Institute for Prospective Technologies Studies. Feebate and Scrappage Policy Instruments

2.5.1 Cars

The time taken for design of vehicles is typically between four and seven years.

Hybrid Vehicle Technology

The concept of hybrid vehicle technology has only really become a competitive option for Japan, US and European markets within the last decade. However, the journey of the hybrid technology process is much longer, with the production of the Lohner Porsche car in 1901 cited by some as the first hybrid vehicle. Created by Jacob Lohner & Co, the drivetrain of the Lohner Porsche could switch between a gas and electric drivetrain[26]. It was not however until the late 1980s that research into the potential for hybrid vehicle technologies began to accelerate, partly as a result of the development of the regenerative braking system. As the core design concept in most electric vehicles, this automotive hybrid technology revitalised the potential for hybrid vehicles in the early 1990s, leading to the development of the Honda Insight and the Toyota Prius, today's most popular hybrid passenger cars.

Globally, the most widely bought hybrid car is the Toyota Prius, hailed by the US Environmental Protection Agency as the most fuel efficiency car on the US market in 2009[27]. Challenged with designing an environmentally friendly, fuel efficient car in 1994, Toyota spent 3 years designing and developing the Prius before the first one was sold in Japan in December 1997. One of the main obstacles in developing a market ready hybrid was ensuring the life of the battery was 7 to 10 years, thus guaranteeing competitiveness with the non-hybrid alternatives. After 4 years of being tested on the market in Japan, the Toyota Prius was sold in the US and European markets in 2001, 7 years after it first started being designed. Since 2001, changes have been made to the model to improve both its environmental and fuel efficiency which (alongside rising fuel prices) has significantly increased the demand for the vehicle.

Plug-in hybrid electric vehicles (PHEVs) have become more widespread in the 2000s, allowing drivers to drive solely by recharging their vehicle from the electrical power grid. Giving drivers the option to travel short distances without the need for conventional fuel through this technology was first seen in 2003 when the Renault Kangoo was released in France but is still in its infancy.

2.5.2 Aviation

The IPCC[60] suggest the following timescales for development and production of aircrafts:

(i)	Technology development preliminary/final design through aircraft certification testing	5 to 10 years
(ii)	Successful production run	15 to 20 years
(iii)	Aircraft lifetime	25 to 35 years
(iv)	Total time span (i) through (iii) to retirement of aircraft series	45 to 65 years

More incremental improvements are also made within individual aircraft model designs over their production lifetime – most significantly in the engines used to power the aircraft.

Concorde

Supersonic airline research in Europe began in 1956 and resulted in the British and French Governments signing an international treaty for the joint design, development and manufacture of a supersonic airliner six years later. The first prototype was rolled out at Toulouse in 1967, but it was

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[26] http://www.hybrid-vehicle.org/hybrid-vehicle-porsche.html

[27] US EPA (2009) "2009 Most and Least Fuel Efficient Vehicles". United States Environmental Protection Agency and United States Department of Energy. Accessed on 3rd September 2009. http://www.fueleconomy.gov/feg/best/bestworstNF.shtml.

not until 1972 that British Airways (then BOAC) ordered five Concordes for its fleet. Concorde made its last commercial flight from New York to London on 24th October 2003.

In 1962 the total bill for the development of Concorde was expected to be between £150 million and £170 million. In December, 1974, the cost to Britain and France of developing Concorde up to the point at which it will enter airline service was then estimated to be £974 million. The three main factors responsible for this sixfold increase are inflation, currency devaluation and design changes[28].

Some have argued that the Concorde programme's primary legacy is in the experience gained in design and manufacture which has since become the basis of the Airbus consortium.

Airbus A380

Market demand for the Airbus A380 was first researched in 1991. Five years later, Airbus developed the 'Large Aircraft Division' to focus research and funding on using large aircraft technologies. Despite the A3XX model being commercially launched in 2000, it was not until 2007 that the Airbus A380-800 was delivered to its first customer, Singapore Airlines. Over this seven year period, components manufacturing started in 2001 with the first engine delivered in 2004. In order to transport the huge components parts to Toulouse in France, surface transport links from France, Germany, Spain and the UK were used in contrast to normal transportation of components by air. After the development of the first engine in 2004 and the subsequent maiden flight in 2005, it took another 2 years for the A380 to be ready for delivery due to certification processes and delays. The delays were partly due to overall configuration management problems of the 530 km (330 miles) of wiring in each aircraft[29].

With aviation vehicles, occupancy is an important condition for assessing the environmental impact of a journey. When full, the fuel consumption of Airbus A380 is around 3 litres/100km/passenger which is more efficient than many passenger cars (depending again on occupancy of the vehicle). Boeing have calculated that the 787 will deliver fuel consumption of approximately 2.4 litres/100km/passenger, assuming average modal load factors, further improving consumption.

2.5.3 Shipping

Shipping development and construction timescales vary greatly depending on the size and function of the vessel. A literature search revealed limited information on timescales, however, it could be assumed given the complexity and size of the vessels they would be similar to those for aviation.

2.5.4 Rail

An analysis of case studies suggests that timescales of around ten years for design and construction are realistic. However, relatively limited information was available.

TGV

The TGV001 is a high-speed railway train built in France, it was commissioned in 1969 to begin testing in 1972. Tests officially concluded in June 1978, though while operational the train never saw commercial use, though it was integral to the design of other TGVs.

In November 2009, Hitachi announced plans to **manufacture railway carriages** to be used on British tracks. The trains will replace existing high-speed models and are expected to be completed by 2018. I.e. the construction is anticipated to be up to ten years. In total, Hitachi plans to build 1,400 hybrid carriages which will be run on lithium-ion batteries and will have diesel engines.

In the UK a fleet of eight **Gatwick Express trains** cost £50 million and took three years to design.

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[28] http://www.concordesst.com/history/eh5.html#n

[29] Kingsley-Jones, Max (18 July 2006). "The race to rewire the Airbus A380". Flight International. http://www.flightglobal.com/Articles/2006/07/18/Navigation/252/207894/Farnborough+first+news+The+race+to+rewire+the+Airbus.html. Retrieved 15th September 2009.

2.6 Time required for changes in infrastructure

2.6.1 Introduction

Estimating the length of time required to secure all of the elements required with major infrastructure works such as funding, the tender process, design, planning approval and the construction phase is difficult. The following sections explore the timescale for a number of key infrastructure changes. These relate to infrastructure changes which would help facilitate modal shift – high speed rail, light rail, cycling as well as those required for new transport technologies for example hydrogen fuel infrastructure.

2.6.2 High speed railways

A number of examples are provided below which suggest that from start to finish the development of high speed infrastructure can typically take 11 to 15 years, but often much more.

- The UK government is currently exploring the potential to develop a high speed rail network across the UK. While no timeframe for this is provided, the Shadow Government's estimated timeframe for delivering completion is 12 years (2015-2027).
- Taiwan recently built a single 215-mile high-speed passenger route for $15 billion. This service commenced in 2007, but plans were formally approved back in 1993.]This is based on completely new infrastructure rather than changes in infrastructure.
- In the 1970s, SNCF (French National Railway) began the TGV high speed train programme with the intention of creating the world's fastest railway network. It came to fruition in 1981, when the first TGV service, from Paris to Lyon, was inaugurated.
- Railways in Italy are one of the most important infrastructure in the country, with c. 19,394 kilometres (12,051 mi) of track. Italy opened what is often regarded as Europe's first high-speed rail route, the *Direttissima*, which from 1978 connected Rome with Florence (254 km/158 mi); the major works were completed in the early 1990s.
- There is a high speed rail connection currently under construction to link Bologna and Florence. Construction on this line started in 996 and it is due to open in October 2009, amounting to a 13 year construction time.
- Construction on the Channel Tunnel, connecting France and Great Britain by rail under the English Channel, began in 1988 and opened in 1994.

2.6.3 Light rail

Timelines for large-scale rapid transit systems from inception to service launch and show the amount of time city structures take to adapt are shown in Table 4. The length of time from inception to launch varies from 7 to 9 years.

Table 4: Rapid transit systems development

	Initial proposals	Permission granted	Service commenced	Cost
Manchester Metrolink	1984	1988	1992	£42.5m (1989)
Tyne & Wear Metro	1971	1973	1980	unknown
Dockland Light Railway (London)	1980	1984	1987	£77m (phase 1)
Amsterdam Metro	1968	unknown	1977	unknown

2.6.4 Cycling infrastructure

Timescales for the introduction of cycling infrastructure vary depending on the type and extent of measure, and can often be linked to the provision of road infrastructure.

- The Copenhagen Cycle Track Priority Plan 2006-2016: the realisation of this plan includes an addition 65 kilometres of cycle tracks.
- Exeter's (as a UK cycling town) infrastructure priorities for 2008 to 2011 include extending cycle routes to communities outside the city, the creation of secure parking facilities, continuing links to schools and employment areas plus a number of public transport interchanges.
- Bristol (as the UK cycle city) includes over 50 infrastructure related schemes over the time period 2008 to 2011.

2.6.5 Hydrogen fuel infrastructure

Developing a hydrogen fuel infrastructure for transport is essential for the uptake of this technology. Structures to enable the delivery of fuel from the point of production or delivery with the point of demand pose challenges in terms of time and cost. In developing a full hydrogen economy in the future, production methods could be either centralised or distributed.

In a centralised system, energy generation and use need are separated for vehicular transport where large-scale, centralized facilities with improved efficiency produce fuels. In a distributed structure, small regional plants or even local filling stations could generate hydrogen using energy provided through the electrical distribution grid. The production efficiency of a centralised system needs to be compared with the benefits of shorter distribution distance in a decentralised structure. These options need to be considered in the design and construction of hydrogen infrastructures.

Traditional natural gas pipelines have to either be coated on the inside or replaced to be able to carry hydrogen fuel and avoid the hydrogen embrittlement of steel. Over 700 miles of hydrogen pipelines have been built in the US. According to GM, 70% of the U.S. population lives near a hydrogen-generating facility but has little public access to that hydrogen[30].

In 2003, California Governor set out a plan for a hydrogen infrastructure for 2010. This vision was to build a "hydrogen highway" composed of 150 to 200 fuelling stations spaced every 20 miles along California's major highways. Currently, only 24 hydrogen fuelling stations are operating in California, most of them near Los Angeles.

2.7 GHG emission reductions – issues to consider

This section considers a range of issues associated with the potential GHG emission reductions that could be gained through the use of new technologies. In terms of the impact of these changes on GHG emissions, issues include:

- Patterns of vehicle ownership and use;
- GHG emissions associated with vehicle manufacture

2.7.1 Patterns of vehicle ownership and use

In terms of GHG impact one aspect is that new cars, which are typically more efficient, are likely to be driven greater distances than older cars. New cars do more of the mileage, but because they are more fuel efficient the GHG impacts are lower than with older vehicles. Data from TREMOVE

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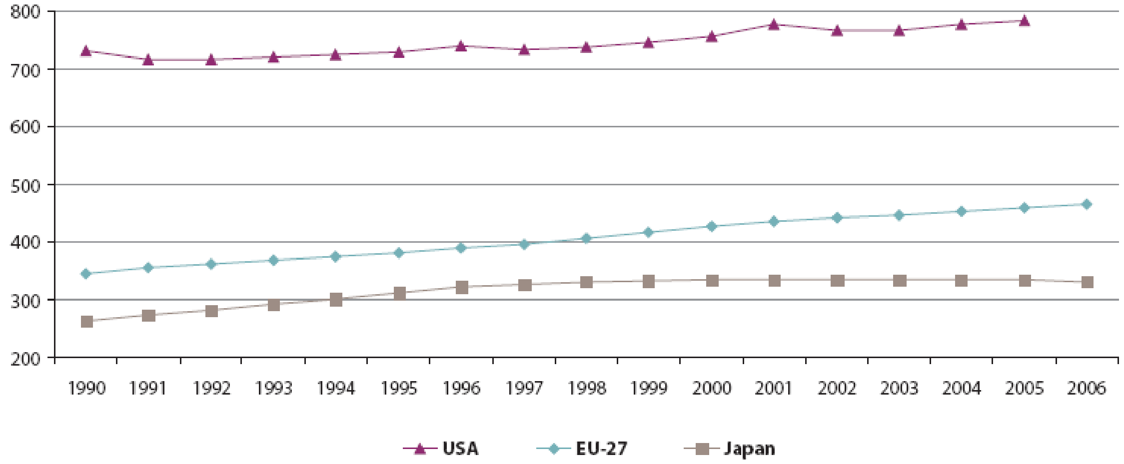
[30] Gross Britta K, Sutherland Ian J, Mooiweer Henk (December 2007). "Hydrogen fueling infrastructure assessment" (PDF). General Motors Research & Development Center. http://www.h2andyou.org/pdf/10Things.pdf. Retrieved 2008-09-19.

suggests that ‘younger vehicles’ may be used more. For example cars under 3 years were 30% of vehicles and 38% of vehicle kilometres[31].

Figure 2.1 shows the number of passenger cars per 1,000 inhabitants in the EU-27, USA and Japan between 1990 and 2006. There has been a steady increase within the EU-27 Member States, rising to 466 passenger cars pr 1,000 inhabitants. Between 1990 and 2005, the number of cars per inhabitant in the EU-27 grew at an average of 1.9% per year, higher than both Japan (1.6%) and the USA (0.4%).

Figure 2.1: Number of passenger cars per 1,000 inhabitants - EU-27, USA and Japan, 1990 to 2006



* includes light pick-up trucks
Note: passenger car stock at end of year n divided by the population on 1 January of year n+1

Car ownership per 1,000 inhabitants in the EU-27 has steadily increased since 1990 (1.9% annual average). However, this growth is not typical across all Member States, and differs quite considerably. 15 of the 27 Member States displayed motorisation rates below the EU average, and of these 15, more than half were new Member States, whose stock grew considerably between 1990 and 2006. Some of the highest rates could be found in Germany (565), Italy (597), France (504) and the UK (471), which had the largest stocks and together accounted for 62% of the EU-27’s total stock of cars in 2006. Furthermore, there has also been an increase in the number of households, which may also change car driving and ownership patterns.

Different types of ownership also need to be considered for example 50 % of new passenger cars sold in the EU are company cars. In terms of penetration of new technologies this should be taken into consideration.

The use of car clubs and car sharing could also play a role in changing travel behaviour. Car clubs are effectively short-term (for example one to two hours) car hire schemes. Cars are typically distributed throughout cities and can be booked at short notice though the internet or over the phone. Car mileage can reduce substantially with reductions of between 28%[32] (Ryden & Morin 2005). and 72%[33] ((Mulheiun & Reinhardt 1999).

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[31] TREMOVE http://www.tremove.org/documentation/index.htm

[32] Ryden, C. & Morin, E. 2005, Mobility Services for Urban Sustainability Environmental Assessment Report, WP6, European Mobility Services for Urban Sustainability, Trivector Traffic AB, Stockholm.

[33] Mulheiun, P. & Reinhardt, E. 1999, "Car-sharing – the Key to Combined Mobility", World Transport Policy & Practice, vol. 5, no. 3.

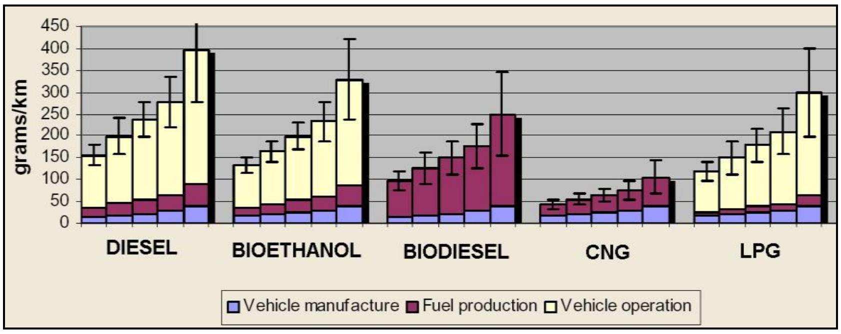
2.7.2 GHG emissions associated with vehicle manufacture

Vehicle replacement has the potential drawback of increasing the amounts of energy and materials used for vehicle construction, dismantling and recycling[34]. For private vehicles emissions are currently as follows[35]:

- Production (production, logistics and energy) is approximately 10%
- Vehicle use (CO_2 from distance driven and after market functions) is around 85% and
- Recycling (CO_2 from managing end of life vehicles) is approximately 5%

In the future the use of new vehicle technologies and fuels will change this contribution. A study by Ecolane[36] illustrates (Figure 2.2) that a passenger car's CO_2 emissions (g/km) vary greatly during its vehicle manufacture, operation and fuel production processes according to the type of fuel used.

Figure 2.2: CO_2 emissions for different fuel production for different stages of the life cycle



The Argonne model[37] calculated energy usage and GHG emissions for the *entire fuel & vehicle life cycle*, which includes the vehicle cycle, the fuel cycle, and the ***vehicle operation*** stages and thus providing a comprehensive view of energy use and emissions.

Results for energy use (Figure 2.3) show that per-mile total, fossil and petroleum energy use for light-weight vehicles (HEVs and FCVs types) is significantly lower than that for conventional internal combustion engine vehicles (ICEV), and that ***vehicle operation*** energy usage account for more than 65% of total energy usage during the entire fuel & vehicle life cycle.

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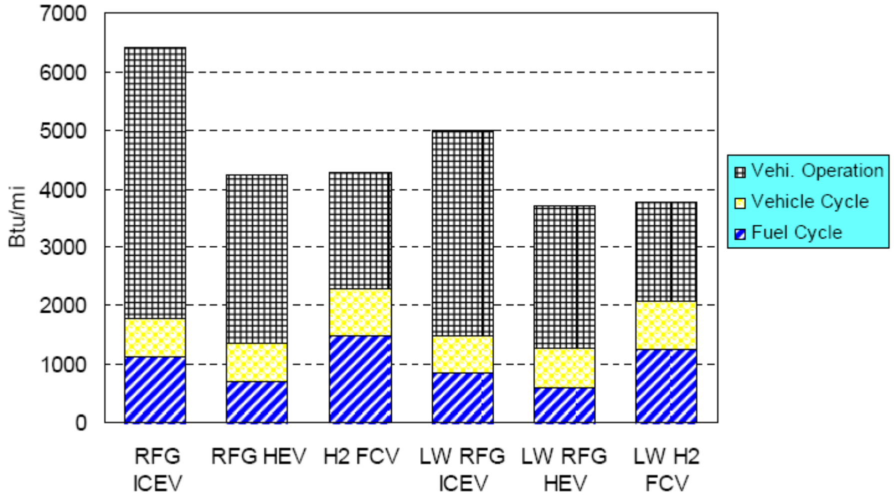
[34] http://themes.eea.europa.eu/Sectors_and_activities/transport/indicators/TERM33%2C2003.09/TERM2003_33_EEA31_Average_age_of_vehicle_fleetfinal.pdf

[35] SMMT (2009) Reference

[36] Ecolane (2006) Life Cycle Assessment Of Vehicle Fuels and Technologies. Report for the London Borough of Camden

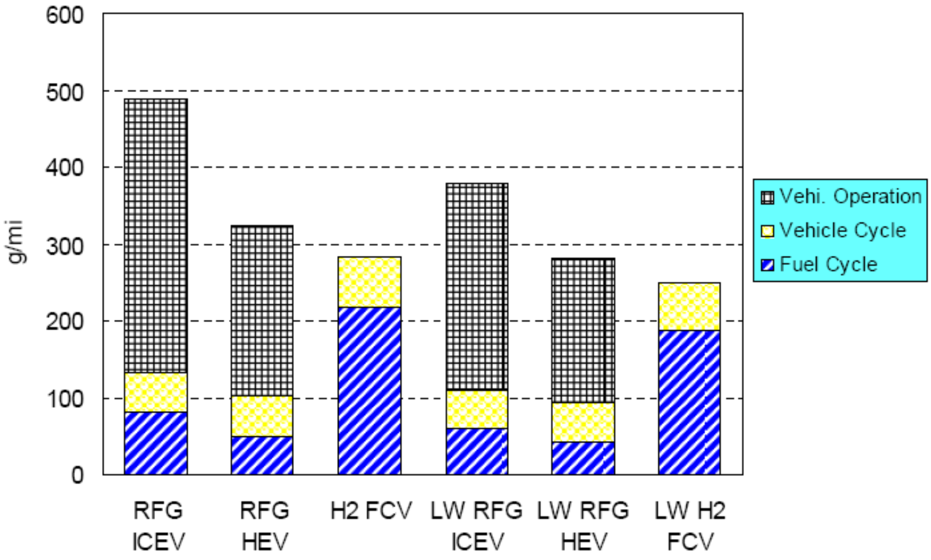
[37] The Argonne model Argonne National Laboratory, Energy Systems Division (2006). *Development and Applications of GREET 2.7 — The Transportation Vehicle-Cycle Model*. Argonne, Illinois, 124 pages.

Figure 2.3 Energy for different vehicle types



As for GHG emissions, shows that for conventional internal combustion engine vehicles, CO_2 emissions during the ***vehicle operation*** phase account for over 70% of the total fuel and vehicle life cycle emissions, while for hydrogen-fuelled vehicles there are no CO_2 emissions during the vehicle operation phase.

Figure 2.4 CO_2 emissions for different vehicle types



AEA used SimaPro Life Cycle Analysis software to provide information on the CO_2 emissions associated with the manufacture of planes and ships, reflecting that there was limited literature available on lifecycle analysis for these modes. SimaPro suggested that:

- Manufacture of planes is around 4% of GHG emissions
- Manufacture of ships is around 2% of GHG emissions

This would reflect the longer lifespan and greater use of these modes.

2.8 Potential implications for GHG emissions

Vehicle lifetimes will have implications for transport GHG emissions savings, as will the time taken for design and development and market penetration. The extent of the impact depends on a number of issues. The first two examples provided below, are perhaps 'worst case' scenarios (note that lifetimes for planes are considered on a par with rail and shipping).

- For cars, assuming it takes seven years to design and develop a car that is market ready. It would then take up to twelve years for it to fully penetrate through the fleet. Therefore full GHG emission saving would not be realised for 19 years. If a maximum age of 20 years is used it would take 27 years.
- For planes, assuming it takes 15 years to design and develop a market ready plane, and ten years to produce. It would take a further 30 years for it to fully penetrate the fleet. Therefore full emission savings would not be realised for 55 years for complete redesigns.

However, clearly there would be GHG emission savings prior to complete market penetration and design and development for these modes is already underway. For example:

- For cars assuming it takes three years to complete the design and development and six years for penetration of 50% percent of the fleet. Within nine years 50% of savings could potentially be achieved.
- For planes assuming it takes seven years to complete design and development, five years for production and 15 years for penetration of 50% of the fleet. Within 27 years, 50% of savings could potentially be achieved. In addition, improvements (mainly in engine technology) are generally still introduced incrementally throughout a base model production lifetime enabling more gradual improvements to be achievable in a shorter timescale.

The actual GHG savings are, however, subject to a number of further considerations including:

- The 'in use' emissions savings offered by the new technology.
- The lifecycle emissions produced by new and existing technologies. For example emissions associated with production and disposal may increase for new technologies.
- The lifetime of the new technologies. With the manufacture and disposal contributing a greater element of lifecycle emissions for vehicles with short lifetimes.
- Whether the vehicle will replace or complement the existing vehicle. Patterns of use of the vehicles could significantly impact on the total GHG.
- If new vehicles are complementing existing vehicle, the mileage driven by the new, more efficient vehicles will need to be taken into consideration. Reflecting that the mileage is likely to be higher for these vehicles and therefore overall emissions lower.

In terms of the modelling elements for this project it will therefore be important to test a range of scenarios.

The timescales for infrastructure varied greatly, with local infrastructure, for example cycle and light rail networks, being implemented on shorter timescales than larger scale, national infrastructure. National networks of locally based infrastructure solutions could aid the reasonable reduction of GHG emissions on relatively short timescales, particularly if building on existing infrastructure (for example cycle routes). This would of course be subject to the development and planning of these schemes. National networks, while taking longer could be implemented on timescales comparable with the development of planes, rail and shipping. However, further consideration also needs to be given to the emissions associated with the production of new, large-scale infrastructure, research suggests that this can be significant[38].

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[38] Chester M.V. and Horvath A Environmental Assessment of Passenger Transportation should include infrastructure and supply chains. Environmental Research Letters 2009.

3 Barriers and Opportunities

3.1 Introduction

This section considers the barriers and opportunities as they relate to new technologies. This includes those at the research and design stages and those when the technologies are introduced. The latter includes:

- Regulatory;
- Economic;
- Social and attitudinal;
- Physical resources; and
- Technical.

3.2 Research and design of new technologies

There are a range of barriers and opportunities associated with research and design (R&D), all of which have the potential to support or undermine the development of new technologies or concepts. These barriers include:

- Coordination or timing;
- Duration of the design process;
- Industry conservatism; and
- Funding of R&D.

3.2.1 Coordination / timing

Several of the main barriers relate to coordination or timing. Firstly, there is the issue of common standards or codes, without which there can be a reluctance to invest in new systems or technologies. Alternatively, where R&D does occur it can be wasted if the fruits of that research become obsolete when another system becomes the technology of choice.

There are also instances where a common standard could facilitate a more desirable product. For instance, if car manufacturers were able to agree to a common battery standard for electric vehicles (EVs) then there could be scope to implement a widespread network of battery swap stations. In turn this would allow the driver to extend the range of the vehicle, which is one of the key barriers to EVs. That said, this is a complex issue because the battery is by far and away the single most expensive component for EVs. Consequently, car manufacturers are designing new business models, including battery leasing, to allow private buyers and businesses to spread the cost and mitigate some of the risk. As a result car manufacturers have so far resisted calls for a common battery standard.

Remaining on the theme of coordination, another potential barrier is a lack of coordination between research groups, both academic and industrial. This can lead to overlaps in certain areas of research and key gaps in other areas, in other words, an inefficient use of research resources. Again, there is an opportunity for the public sector to play a role here. The hydrogen fuel cell sector suffered from problems of this nature and the EC responded by setting up the Fuel Cell and Hydrogen Platform, which in turn led to the Fuel Cells and Hydrogen Joint Undertaking. The aim of the latter body is to implement the R&D targeted by the EU that is needed to support the market introduction of hydrogen fuel cells.

The final barrier with regards coordination relates to the timing of investment in infrastructure and technology R&D, which particularly applies to new vehicle energy storage technologies such as EVs and hydrogen fuel cell vehicles (FCVs). Without careful management there is a risk that a lack of R&D investment in either the charging/refuelling infrastructure or the fundamental energy storage technology could delay or prevent widespread uptake. Both strands of R&D need to take place in parallel, which once again presents an opportunity for Member State Governments and/or the EC.

By taking a high level view they will be able to monitor the relative progress of each strand of research and take steps to accelerate activities where appropriate.

3.2.2 The duration of the design process

The duration of the design process (e.g. typically 5 year design cycle for cars) can represent a barrier in itself. Manufacturers of vehicles for all modes commit themselves to significant investment[39] when choosing to proceed with a new model. When making this investment they cannot be totally certain how the regulatory or policy framework will evolve. In addition, they cannot be sure how the world and European economic outlook pan out nor how consumer preferences might change. All these issues represent risks that might dissuade manufacturers from investing in R&D for new technologies or concepts.

3.2.3 Industry conservatism

The operators of certain modes of transport (e.g. rail and aviation) have a significant influence on the design of vehicles. The lifetime of trains and planes can exceed 30 years (although many European airlines will renew their fleet well before then, selling the aircraft on) so there is a natural tendency to take a conservative view with regards the equipment fitted to the vehicles. If a shortcoming was discovered with a new technology it could prove costly for the manufacturer to correct and inconvenient for the operator if a significant proportion of their fleet was taken out of service. This represents a barrier to technological innovation and new concepts since manufacturers are more inclined to take the ‘safe’ option. Furthermore, where new technologies or concepts are introduced a raft of tests and checks must be undertaken to satisfy the safety regulators. Ultimately this means manufacturers incur even higher costs before being able to launch a new technology or system, which once again is a barrier to investment in R&D.

3.2.4 Funding of R & D

This leads on to the final barrier, which relates to funding R&D to take an early prototype and develop it into a commercial proposition. The difficulty that academics and to a lesser extent industry face, is that the investment at this stage in the development process will not generate a financial return. This is a key area where Member State Governments and EC might look to intervene to fund tests, trials and demonstrations to help academics and manufacturers bridge the gap between a good idea and a commercially viable product.

3.3 Barriers and opportunities associated with the introduction of these technologies

3.3.1 Introduction

This section relates to barriers and opportunities associated with the introduction of these technologies. It considers:

- Regulatory;
- Economic;
- Social and attitudinal;
- Physical resources;
- Knowledge resources; and
- Technical.

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[39] http://www.businessinsider.com/developing-nissans-electric-car-cost-significantly-above-500-million-2009-7

3.3.2 Regulatory

Until relatively recently the transport sector has not been subject to significant regulation of GHG emissions. This is one of the key barriers to introducing new low carbon technologies, which are often more expensive than conventional technologies. Competition between manufacturers and voluntary agreements can produce some fuel economy and hence carbon emissions performance improvements as illustrated in the aviation and road sub-sectors.

In response to this barrier the EC brought aviation into the EU Emissions Trading Scheme from 2012 and developed the CO_2 Regulations for cars, which are phased in between 2012 and 2015. There are further opportunities to bring in similar regulations for the light commercial vehicle (LCVs) and heavy goods vehicle sectors (HGVs). Whilst these new regulations are prompting manufacturers to develop incremental technologies (particularly in the road transport sector where advanced diesel and gasoline engines as well as hybrid technology will cut tailpipe emissions in the short to medium term) they do not incentivise the development of ultra low carbon technologies to quite the same extent. This is because neither the EU-ETS nor the CO_2 regulation for cars set long term targets, which represents another key barrier.

Without the certainty of regulations to compel them to make deep cuts in GHG emissions in the long term there is little incentive for manufacturers to either develop new ultra low carbon technologies with any great urgency or market them aggressively to consumers. For instance, most car manufacturers are developing EV, FCEV or plug in hybrid vehicles (PHEV) but very few have announced significant manufacture volumes.

This barrier is linked to the uncertainty associated with the long-term policy framework. It is not currently clear whether Member State Governments and the EC will maintain a technology neutral approach or begin to prioritise particular technologies. This is important because road technologies such as EVs and FCEVs will need a sizeable investment in recharging/refuelling infrastructure to achieve significant penetrations, which in turn will require support from Governments. It is hard to envisage two sets of infrastructure being developed so there may be a need for a choice between the two technologies. Until such choices are made, or the EC and Member State Government’s plans are determined some manufacturers will understandably be rather reticent to push certain technologies too hard.

Safety concerns and safety regulations could also become a barrier for new technologies for all modes. Risk assessments are a key part of most major developments so the theoretical risk of say a hydrogen tank exploding may prove to be a significant issue for local planners when deciding whether to give permission for construction of a hydrogen refuelling station. In reality hydrogen is likely to be safer than gasoline (given that it is less flammable and disperses naturally) but ingrained beliefs are sometimes difficult to change. On a related note, some regulations and procedures for the emergency services may need to be rewritten or rethought to accommodate new fuels. For instance, would an EV or FCEV vehicle fire need to be dealt with differently in view of the lithium (which is highly combustible) in the lithium-ion batteries? Whilst these ought not to be major issues the bureaucratic burden associated with amending a significant number of procedure and guidelines should not be underestimated.

3.3.3 Economic

New technologies or concepts are frequently more expensive than existing technologies from a capital expenditure perspective. The gap or ‘marginal capital cost’ often narrows if the new technology reaches mass manufacture but a price premium can still remain. Despite the fact that many novel technologies reduce operating costs, this marginal capital cost can still be a significant barrier.

In the short term Governments can use so called ‘up front price support’ to cover some or all of this marginal cost and ensure a technology gains a foothold. However, schemes of this nature are expensive so they tend to be implemented sparingly. Assuming the funding for upfront price support is in place there are some ways of maximising its effectiveness. The first vehicles that employ a new technology (that significantly alters the user experience) tend to be the hardest to sell. Therefore, upfront price support can be tapered so as to provide larger grants to the early adopters and progressively lower grants as sales volumes increase.

A key barrier to the introduction of new transport technologies from an economic perspective is the way in which many external costs have as yet not been fully internalised. Many new transport technologies seek to address impacts (such as GHG or air quality emissions) that are not factored into the cost of providing a transport service. The obvious exception to this is aviation, which will be joining the EU emissions trading scheme (ETS) from 2012. However, there are no firm plans to include road, rail and shipping in the scheme so these sub-sectors form part of what is termed the 'non-traded' sector. Ultimately, this means the external costs are frequently undervalued, particularly by the private sector, during the decision making process. Consequently, if a new technology is more expensive in terms of capital costs, as is often the case at least initially, it can be hard to make a compelling business case for investment.

Funding for new infrastructure is also a barrier, particularly for technologies such electric or hydrogen fuel cell vehicles. In the short-term public sector bodies (e.g. Governments, local authorities, Government Agencies etc) may be willing to fund the construction of local demonstration networks. However, a comprehensive network of charging or refuelling points across Europe would cost many billions of Euros so that would clearly be far more challenging for public sector bodies to fund. In reality consumers may have to pay for the network via some kind of levy on the hydrogen or electricity they draw from the network. Perhaps there could be a role for Governments in underwriting the investment.

Alternatively, as a natural monopoly the infrastructure could be made part of the regulated asset base. The network operator would propose funding levels to develop the network via price controls every 5 or 7 years. The main input to this process from the network operator would be a document setting out the infrastructure they wished to build and the justification for the investment. The role of the regulator could be to protect the interests of consumers and help the Government achieve its overarching objectives. To that end they would review the network operator's proposals and approve or reject each individual infrastructure project based on a series of criteria such as cost effectiveness and strategic importance. The network operator could be a private sector company or a Government owned body.

3.3.4 Social and attitudinal

A poorly informed public may present a further barrier to infrastructure deployment. A lack of understanding about a new transport technology is likely to make stakeholders sceptical of its potential. By increasing the knowledge of both the potential and risk of a new technology, users and institutions will be better informed about their technology options. Increasing the knowledge of stakeholders about new technologies can be achieved through two main channels: firstly by publicising existing projects to raise the profile of a technology and secondly by inviting stakeholders to engage in the development process of a new technology.

For example in the UK at the Hydrogen refuelling centre at Hornchurch, lack of engagement with the local community was cited as key to the failure to gain local acceptance and support at the early stages of the project. However, it was felt more generally that the local authorities are also poorly informed about the true risks and potential of hydrogen fuel and hydrogen-fuelled transport. It was felt more could be done to promote positive stories about hydrogen and that demonstration activities could be used to prevent the subject falling off the public radar and to improve public understanding. Joffe (2006) believes achieving a positive perception of hydrogen could be one of the most serious challenges for the introduction of hydrogen infrastructure in London[40].

Penetration of new technologies also strongly depends on the often 'perceived' added value of the product. If greenhouse gas emissions reductions (and the associated fuel reduction) are the only added value elements, and this is something that is not high on the consumer's list of priorities, then

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[40] Joffe (2006) London Hydrogen Partnership.
http://www.fuelcellmarkets.com/london_hydrogen_partnership/news_and_information/2,1,1676,1.html

it will take a long time to penetrate the market. However, if it is high on the list of priorities for the consumer, then penetration into the market will be achieved rapidly.

3.3.5 Physical resources

The price of a key material can have a strong effect on the overall price of a technology. For example, the price of lithium ion (li-ion) batteries is strongly influenced by the price of the cathode. One of the most common cathode chemistries is lithium cobalt oxide. Unfortunately the price of cobalt has fluctuated from 15$ per lb to 50$ per lb in the last year alone, which has had a significant impact on the overall cost of the batteries. The price of lithium also impacts the cost of li-ion batteries.

Price fluctuations of this nature can be driven by a range of factors. Scarcity of the material in question is often a key driver as is the ease at which reserves can be extracted. It may only become economic to mine a particular material once the price rises beyond a certain level. The demand for a material can also have a strong impact on its price even when reserves are plentiful. This can be because of capacity constraints in certain processing or manufacturing techniques. For instance, the cost of diesel in the UK has been inflated in recent years, where it costs significantly more than gasoline, due to a shortage of refining capacity. In contrast, in much of the rest of Europe diesel is cheaper than gasoline.

Overall reserves of key materials, or *estimated* reserves, can also prove to be a barrier to a new technology. Limited or rapidly diminishing reserves of a key material will clearly impact upon the likelihood of a new technology gaining a foothold in one or more markets. Interestingly, there has been much debate in recent times regarding the extent of lithium reserves. Some commentators argue that reserves are plentiful, particularly in light of moves by the Bolivian Government to develop the Uyuni salt fields, which are thought to be the largest lithium reserves in the world[41]. Other commentators are of the opinion that current estimates of reserves have been overstated. This illustrates the fact that estimating reserves is far from an exact science, which in certain circumstances could be a barrier in itself due to the uncertainty or doubt it creates in the minds of decision makers.

Finally, it is important to bear in mind that recycling or re-use of materials can be a powerful tool to combat the issue of limited reserves. Returning to the lithium-ion batteries example, there has been concern in some quarters that there may be insufficient reserves of lithium to meet world demand. Given how crucial li-ion batteries are to the function of EVs (they are much more energy dense than other types of batteries, ensuring they are a much more manageable size) this would clearly impact on the prospects for the technology. However, recent work by the Argonne National Labs in the US[42] illustrated that US demand for lithium in 2050 could be reduced from 50,000 tonnes to 12,000 tonnes through recycling. That said, these numbers are based on very optimistic assumptions regarding uptake of EVs and recycling rates.

3.3.6 Technical

There are a number of technical issues these include:

- It has to work (i.e. be good enough, offer comparable performance or even an added value)

- **Conflicting prerequisites.** The technical production of new technologies can in cases suffer from a ‘chicken and egg’ problem where it is unclear whether it is better to develop new vehicles or new infrastructures first. Research suggests that significant numbers of drivers would be willing to switch to an alternative fuel if the new fuel was available at approximately 25% of existing retail stations[43]. Implementing wide-scale refueling stations is extremely costly and poses the technical challenge of identifying their optimum location.

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[41] http://evworld.com/article.cfm?storyid=1457&first=6411&end=6410

[42] http://www.transportation.anl.gov/pdfs/B/584.PDF

[43] Van Benthem, A., G. Kramer, R. Ramer (2006) “An options approach to investment in a hydrogen infrastructure.” *Energy Policy* **34**: 2949 – 2963.

- **Storage and distribution** In addition to understanding where to build refueling infrastructure, storage and distribution of new fuels between these infrastructures is a potential technical barrier to developing new technologies.

- **Technical performance** of new technologies can be a barrier. For example the performance of fuel cell vehicles (FCVs) has been a historic barrier with vehicles not being able to deliver the necessary mix of power density, lifetime and performance at a competitive cost[44]. Historically, the length of a fuel cell's operational life has also been an area of concern. These barriers have been minimised by investment and improvement in the technologies of fuel cell vehicles in recent years.

- **Maintenance of the technologies can be a barrier.** For example fuel cell maintenance is focused on resupplying hydrogen fuel because the cells have no moving parts. Encouraging the widespread development of fuel cell technologies will require specially trained technicians for maintenance support. Vehicle dealerships will initially have to meet the maintenance demand for this new technology, training and certifying maintenance technicians in new processes.

- **Issues over reuse, recycling and disposal. This offers opportunities as well as barriers.** For example Hybrid vehicles have components that are capable of being recycled in a higher proportion of their total social energy costs than non-hybrid models. A larger amount of light-weight metals and plastics have a higher desirability for recycling, therefore making more of a hybrid vehicle's non-electronic components desirable for scrapping or recycling. Hybrid vehicles mostly use Nickel metal hydride (NiMH) batteries, which are benign, therefore making them fully recycled.

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[44] Eoin Lees Energy, E4Tech, ElementEnergy (2004), "A Strategic Framework for hydrogen energy in the UK"

4 Case Studies

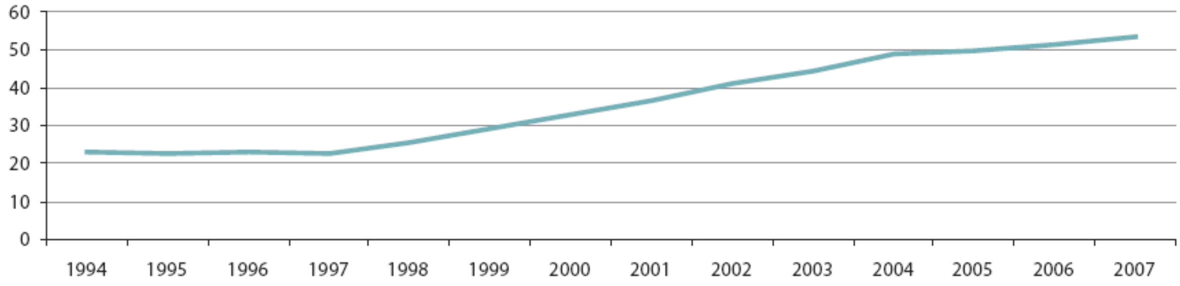
The following case studies provide examples of how long it has taken for technologies to penetrate the market in the past and barriers and opportunities that have occurred in the implementation:

- Dieselisation,
- Hybridisation
- The take up of LPG
- Electric vehicles
- Added value safety measures

4.1.1 Rates of dieselisation in Europe

The potential for diesel to replace petrol as the preferred fuel for passenger cars was identified back in the early 1970's, and the proportion of diesel powered passenger vehicles has increased. The highest yearly percentage-point (pp) increases in this share were displayed by Austria (2.9 pp), Malta (2.3 pp, 1998 to 2002), Spain (2.2 pp) and Luxembourg (2.2 pp, 1994 to 2001), and the lowest by Denmark (0.3 pp, 1994 to 2002), Cyprus (0.3 pp), Sweden (0.2 pp) and Ireland (0.1 pp). The trend is underlined by diesel fuel's growing share in the final consumption of petroleum products, a share which grew in most Member States, and which, on average in the EU-27, rose from 41.3 % in 1990 to 61.5 % in 2006.[45]

Figure 4.1: Share of diesel in new passenger car registrations, EU-15 (%)



The success of diesel technology in Europe is sustained by technological improvements and more specifically by the direct injection "common rail" or particle filters. These efforts are designed to limit pollution of diesel and raise engine performance.[46]

Up until 1987 Germany and Italy maintained a strong position in the diesel market. However production of diesel vehicles in these countries began to fall in 1985-86 due to increases in taxation of diesel vehicles. Some countries such as Belgium and Germany tax diesel fuel approximately 20% less than petrol but annual vehicle tax for cars running on diesel is higher as that is linked into journey lengths.

France is the world leader for diesel private vehicles – approximately 70% of vehicles are diesel. This is due in part to taxation policies, which include the following:[47]

- From the early 1980s taxes on gasoline were increased at a high rate and taxes on diesel much less in order to protect the competitive position of French hauliers.
- Pump prices of gasoline contain a tax share of 78% whereas diesel has a tax share of 72%.

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[45] Eurostat (2009) Panorama of transport, EC, Luxembourg http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-DA-09-001/EN/KS-DA-09-001-EN.PDF

[46] Mutual Influence of Innovative Choices Made By Industrialists (Case Study of the Diesel technology) and Community Environmental Standards (2007) Dr Marine Moguen-Toursel. Centre for Historical Research, EHESS (Paris) http://www.unige.ch/ses/istec/EBHA2007/papers/MoguenToursel.pdf

[47] IEA Energy Policies of IEA Countries

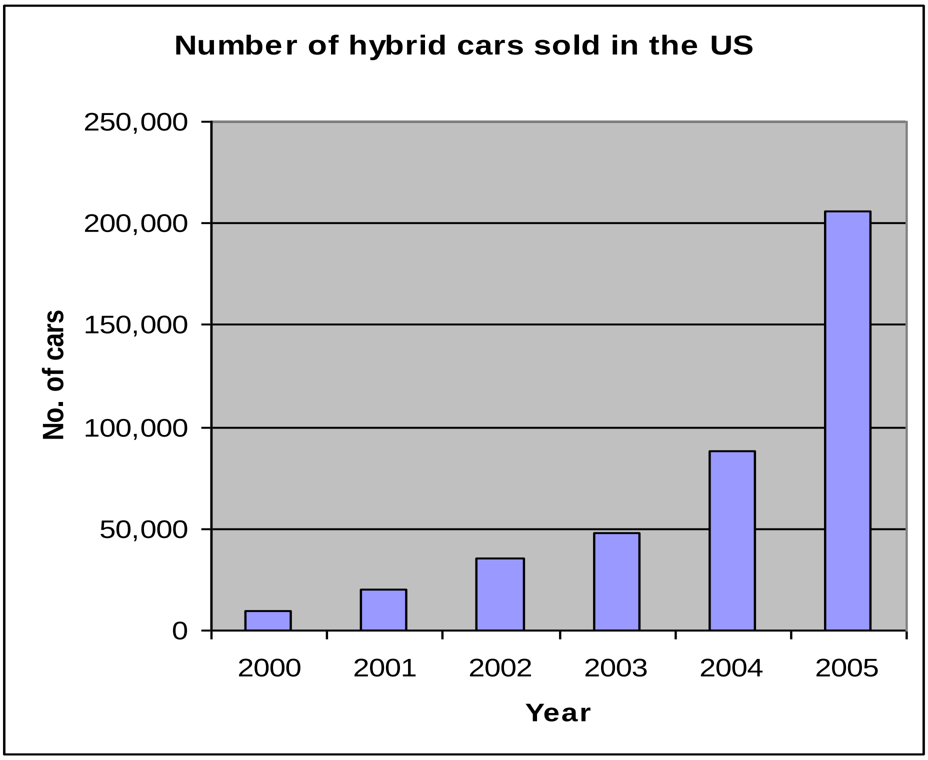
- In 1999 steps were taken to reduce the differential due to health concerns and the economic impacts of France exporting gasoline and importing diesel.
- The September 2000 fuel protests resulted in further changes linked to VAT which continued to result in favourable options for diesel.

4.1.2 Rates of hybridisation (hybrid cars) in US

Hybrid vehicles have two or more major sources of propulsion power, typically combining an internal combustion engine with electric motors. A hybrid vehicle has the ability to be powered by either one of these systems independently or both together.

Sales of hybrid cars in the US increased by a reported 48.6% in August 2009 compared to August 2008.

Figure 4.2: Number of hybrid cars sold in the US



Reasons behind a hybrid shift in the US[48] include:

- Federal incentives
- State and City incentives and perks
- Employer incentives and perks
- Loan discounts
- Insurance discounts
- Improvements in repair costs and braking systems
- Resale value improvements
- Savings in fuel costs

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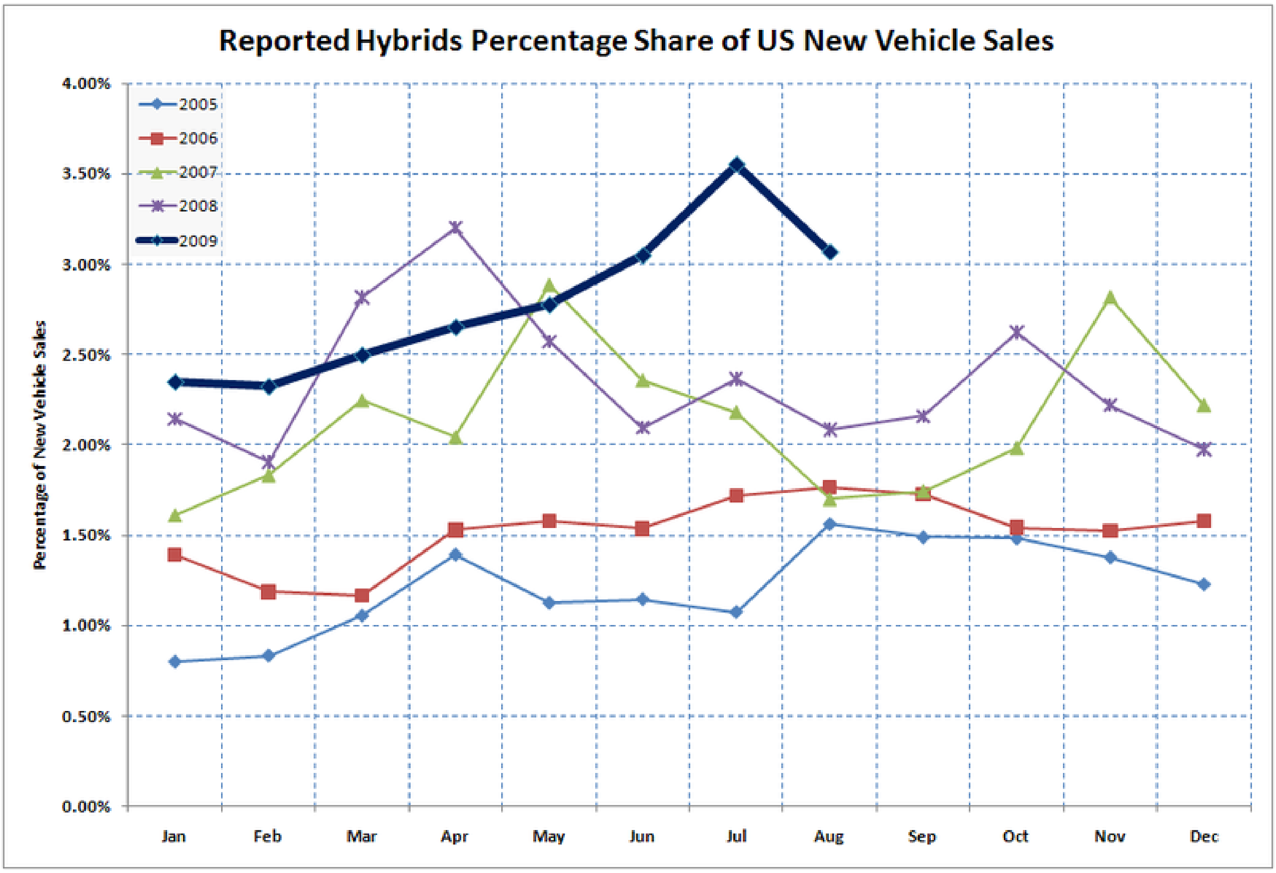
[48] The Money Saving Perks of a Hybrid Car. Spring 2009. http://www.coopamerica.org/pubs/realgreen/articles/hybridcars.cfm

Figure 4.3 Market share of reported hybrid sales in the US [49]



The total uptake share of hybrid cars is still very small (at 3%, but the rate of hybrid sales is accelerating.

Certain barriers need be addressed to stimulate sales of hybrid cars in the US (and beyond). These include:

- Cynicism towards hybrids over their true green credentials (manufacturing & lifecycle impacts e.g. extra components, battery nickel sourcing and disposal)
- Poor performance, including slower acceleration
- Price. Still considerably more expensive than similar class cars. However, incentives and fuel savings may help offset some of these costs.
- Maintenance.

4.1.3 Take up of LPG

Liquefied petroleum gas (LPG) autogas is well established worldwide as an environmentally friendly transport fuel in use in over 12 million vehicles and is the most widely available alternative fuel in the UK. Over the last ten years, the UK LPG market has grown to around 150,000 LPG vehicles on the road. This is less than 1% of the total market.

Around 60% of the world supply of LPG comes from the separation of natural gas products, and 40% is a by-product from the refining of crude oil. The UK produces around 5.8 million tonnes of which

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[49] http://www.greencarcongress.com/2009/09/hybrid-sales-20090902.html

over 2.5 million tonnes is exported prompting the notion that shifting to LPG has the potential to decrease the UK's reliance on fuel imports[50].

LPG conversion grants were first made available in the UK in 1996, under the government-sponsored TransportAction PowerShift programme. This was set up to 'kick-start' markets for clean fuel vehicles running on LPG, natural gas and electricity. A critical objective of the Powershift Programme was to try and get LPG vehicles onto the production line, avoiding the need for aftermarket conversions. This would thus improve emissions performance and reduce the premium cost of vehicles[51].

In November 2001, the UK government attempted to promote a substantial leap in the number of motorists switching to by extending eligibility for conversion grants, to vehicles up to five years old. Grants were made available for up to 50% of conversion costs to LPG, depending on the level of emissions improvement of a vehicle (typically making grants ranging from £1,300 to £1,800 available). At this time, LPG was available at approximately 900 UK filling stations compared with the 1,300 today[52].

The government launched the 'Boost LPG' initiative in April 2003 to increase the availability of LPG fuel in rural areas, such as the Scottish Highlands and Islands, East Anglia and Cornwall. Under this scheme, the Government gave grants to garages to help them become accredited LPGA converters[53].

The culmination of UK Government backed incentives meant that LPG was an attractive alternative fuel option, mainly because it was half the price of petrol and the Powershift grant meant users could offset 70% of the conversion cost through the government-funded scheme[54]. However, following an increased levy on LPG, and the abolition of the Powershift grant, LPG is a less viable alternative that it was before, therefore, stifling any further development. An increased interest in biofuels overs the last decade has increased competition within the alternative fuels market.

4.1.4 The electric car in the US

The first electric cars can actually be dated back to 19th Century. At the turn of the century 38% of cars were electric powered, 22% gasoline powered and 40% steam powered. However, the cost of gasoline vehicles fell gradually throughout the early part of the 20th Century and by the 1920s, electric cars dominance had passed, and a decade later, the American electric automobile industry had effectively disappeared.

Therefore it took 30 years for a technology to go from 38% to 0%. This was presumably driven by greater range and attractiveness of alternative ie gasoline.

In the early 1990's General Motors is rumoured to have spent in the region of $1 billion creating the EV1 electric car after the California Air Resources Board (CARB) passed the Zero Emissions Vehicle (ZEV) mandate in 1994 for zero emissions vehicles. However, the mandate was reversed in 2001 after political objections and lobbying from the oil industry.

Under pressure from various manufacturers and political lobbying, CARB replaced the zero emissions requirement with a combined requirement of a very small number of ZEVs to promote research and development, and a much larger number of partial zero-emissions vehicles (PZEVs), an administrative designation for a super ultra low emissions vehicle (SULEV), which emits about 10% of the pollution of ordinary low emissions vehicles and are also certified for zero evaporative emissions. While effective in reaching the air pollution goals projected for the zero emissions requirement, the market effect was to permit the major manufacturers to quickly terminate their electric car programs and crush the vehicles.

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[50] http://www.drivelpg.co.uk/about_lpg.php
[51] http://www.dft.gov.uk/pgr/roads/environment/cvtf/finalupdatereportofthecleane3791?page=1
[52] http://www.edie.net/news/news_story.asp?id=4775
[53] http://eeru.open.ac.uk/natta/renewonline/rol45/8.htm
[54] http://www.roadtransport.com/Articles/2009/09/11/134569/lack-of-incentives-stifling-green-agenda.html

General Motors have placed forward several reasons for the abandonment of the EV1: they claim there was little or no consumer demand, that the battery power used within the car was unsuitable for long distance travel, that customer feedback suggested there were many difficulties with the vehicle and that there was a general feeling that the technology was not yet ready amongst consumers. Almost all EV1s were found to have been crushed; GM never responded to the EV drivers' offer to pay the residual lease value ($1.8 million was offered for the remaining 78 cars in Burbank before they were crushed).

This episode seriously hindered the development of the electric car industry at a time when it could have made significant progress. It is clear that political, economic and commercial factors need to be aligned to ensure that new technology in this area can develop.

4.1.5 Added value vehicle safety

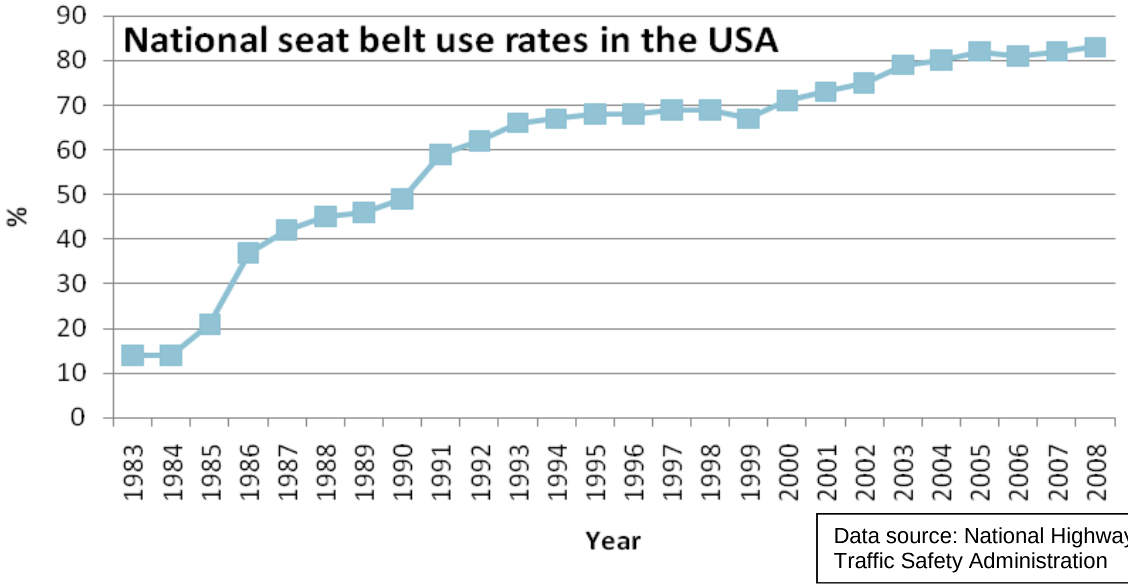
Basic versions of seatbelts were invented in the late 1800s, however, it was not until 1949 and 1955 that American car manufacturers Nash and Ford respectively first offered seatbelts as options in their passenger vehicles. Swedish firm Saab followed by introducing seat belts as standard in their vehicles in 1958. Arguably the most important contribution of vehicle safety, it is estimated that the seat belt has saved one million lives in its 50 year history and reduces the risk of death or injury by over 50%[55].

The 1970s saw the introduction of an audiovisual reminder system, designed to remind the driver and passengers that their seatbelt is not fastened. Wearing front seat belts in Britain was not made compulsory until 1983, and since then is estimated to have saved between 35,000 and 50,000 lives.

Over the last 30 years, the airbag in vehicles has changed significantly, becoming more complex to meet the safety needs of drivers. In the mid-1970s, the airbag was initially marketed as a safety alternative to seat belts, providing similar protection during a collision. Ford built an experimental fleet of cars with airbags in 1971, followed by General Motors in 1973 on Chevrolet vehicles.

Airbags became a federally required safety feature of all passenger cars in the US in 1996. Further safety developments have occurred since then - from 2006 - passenger cars and light-duty trucks in the US must be equipped with sensors that identify children and very small adults and deploy the airbag with less force or not at all.

Figure 4.4 National seat belt use rates in the USA



Data source: National Highway Traffic Safety Administration

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[55] http://www.independent.co.uk/life-style/gadgets-and-tech/features/the-man-who-saved-a-million-lives-nils-bohlin--inventor-of-the-seatbelt-1773844.html

5 Conclusions

The conclusion below identifies key issues to emerge from this paper and identifies factors for consideration in the development of future scenarios.

The lifetimes of the different modes varies considerably with road vehicles tending to have shorter lifetimes than rail, aviation and shipping. Road vehicles also tend to have shorter development times.

In terms of contribution to GHG reduction, one could therefore expect a full contribution from new road vehicle technologies by 2050, but the contribution from new technologies for rail, aviation and shipping would depend on a number of factors. This is not to say that these contributions would not be significant nor vital, just that given the lifetime of these vehicles, full development and market penetration would be more challenging to achieve. Retrofitting offers a number of opportunities for GHG emission reduction from these modes and needs to be fully explored.

- Factors for consideration in the development of scenarios include - what should expectations be with regard to the contribution of different modes and to GHG reduction in the short and longer term.

Key factors in terms of GHG reduction are the use, lifetime and lifecycle emissions of the new technologies. For example if the vehicle will complement rather than replace, if the lifetime is shorter and the lifecycle emissions greater then the GHG reductions from the new technologies are less obvious. Policy measures, which do not take these factors into consideration can have unwanted, unintended impacts.

- Factors for consideration include - are there additional factors which could impact on the GHG reduction potential of new technologies which need to be considered? What steps can be taken to ensure that optimum levels of GHG reduction are achieved? How can we benefit from experience gained previously?

The infrastructure associated with modal shift can be achieved within relatively short timescales. Further consideration needs to be given to the GHG emissions involved in the construction of this infrastructure.

- Factors for consideration – how should GHG emissions associated with the introduction of new infrastructure be treated, over what timescales should it attributed?

A number of barriers and opportunities for the take up of new technologies have been identified. These relate to: regulatory, economic, social and attitudinal, physical resources and technical issues. These include the need for long term policy frameworks, the role of the public sector in short term funding of demonstration schemes, the importance of engagement with members of the public, and the contribution of recycling to optimising physical resources

- Factors for consideration – what further barriers and opportunities could be covered? How can barriers be minimised and opportunities realised?

This report considers five case studies – rates of dieselisation; rates of hybridisation; take up of LPG, electric vehicles and added value safety measres - which reflect, in many ways the outcomes of the barriers and opportunities section. For example the important contribution that fiscal incentives make in the uptake of new technologies and the requirement for clear, consistent long-term policy frameworks.

Annex 1

Cars and other road passenger vehicles

UK MARKAL energy modelling assumes the average lifetime of a car to be twelve years. In the table this is complemented by data from TREMOVE which suggests that lifetimes can increase to 20 years.

Light Commercial and Heavy Goods vehicles

There is little data available on the lifetimes of LCVs and HGVs. AEA has replicated the figures used in this section from the UK MARKAL energy modelling assumptions. Data from TREMOVE for 2010 is also provided.

Railway engines and carriage

Discussions with industry experts suggest that 35 years is a reliable number to use in order to allow for longer than expected lifetimes but ignore major retrofits. Railway engines and carriages will typically last forty years, or considerably more if they undergo major powertrain retrofits. In terms of the original manufacture, they are designed to last 30 years, but in practice exceed this.[56]. UK MARKAL energy modelling assumption is 40 years, but this is likely to be skewed by major retrofits.

The 35 years is reasonably in line with data from TREMOVE.

Inland Waterway vessels

No information was found.

Ships

In the passenger market, an independent source suggests P&O decommission their fleet after 25 years service[57]. Container ships tend to last longer, as can be seen by the extrapolation in Figure A1.1:

Taking the mean of these two results gives 28 years, which was reviewed and agreed within AEA.

This is in line with the age profile of the world fleet, shown in Figure A1.2 whereby vessels over 30 years are not considered. The age profile, using the number of vessels, suggests approximately half of the world's fleet is more than 20 years old. It is worth noting (Figure A1.3) that when gross tonnage rather than the age of vehicle is taken into consideration that ships older than 20 years amount to only 25% of the total gross tonnage, and that in terms of gross tonnage, about half of the fleet is ten years old or less.

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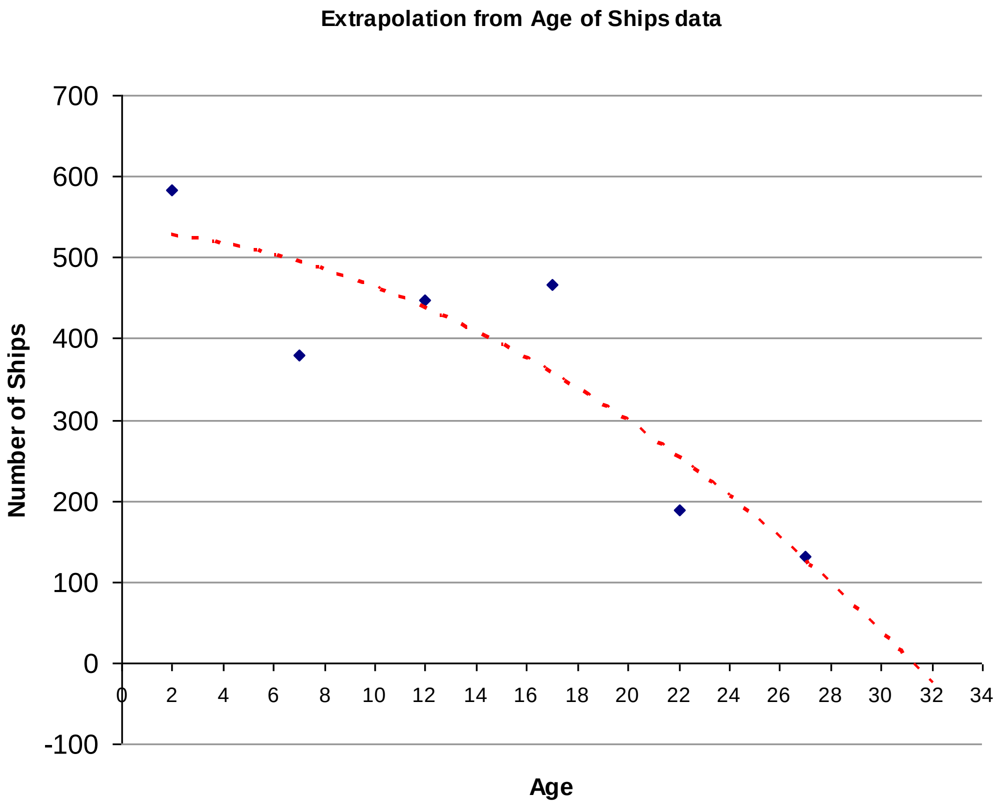
[56] Personal communication with Association of Train Operating Companies

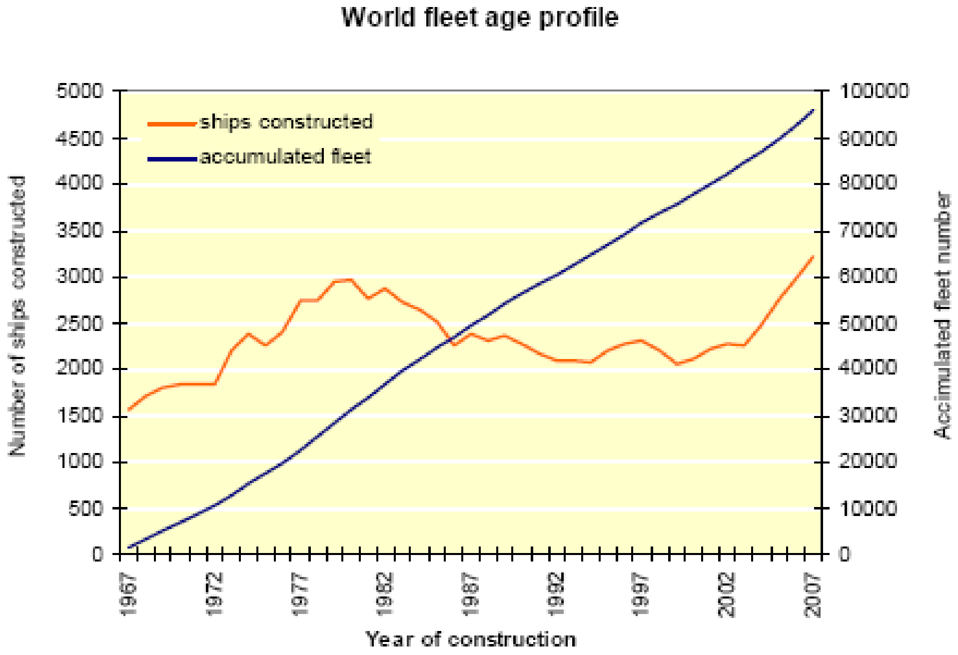
[57] http://www.poferriesenthusiasts.co.uk/fleet/podover/

Figure A1.1: Extrapolation from Age of Ships data



[58]Data points taken from 1997 data in referenced source

Figure A1.2: Age Profile of the world fleet



Source: Lloyd's Register – Fairplay. 2007 in IMO GHG Study (2009)

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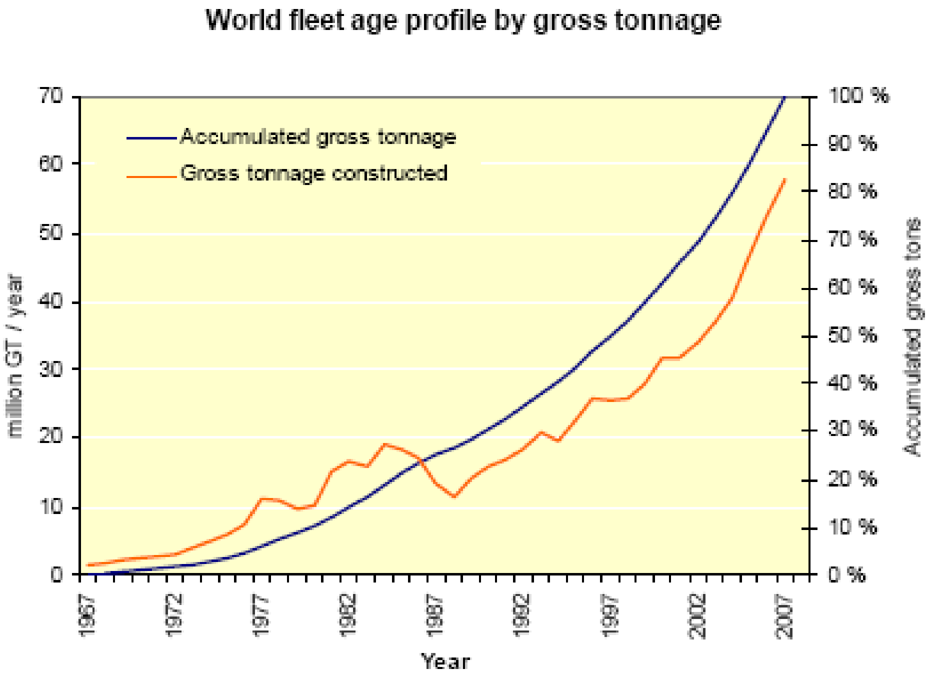
[58] http://www.containerhandbuch.de/chb_e/wild/index.html?/chb_e/wild/wild_07_06.html

Figure A1.3 Age profile of the world fleet by gross tonnage



Source: Lloyd's Register – Fairplay. 2007 in IMO GHG Study (2009)

Aircraft

UK MARKAL energy modelling uses 30 years as the average lifetime for aircraft, and this corresponds with data from 'informal' literature, and from work by the Tyndall centre[59] and the Intergovernmental Panel on Climate Change[60] (which suggests 25 to 35 years). This is reasonably in line with data on average age by manufacturer. http://av-info.faa.gov/GetFleetAge.asp

An issue to consider with regard to vehicle replacement, is that suggest an aircraft's lifespan is measured not in years but in pressurization cycles. Fuselage and wings are stressed, each time an aircraft is pressurised during flight. Therefore, aircraft used on longer flights experience fewer pressurization cycles and can last longer than those on shorter flights[61].

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[59] http://www.tyndall.ac.uk/research/theme2/final_reports/t3_23.pdf

[60] InterGovernmental Panel on Climate Change (2000) Aviation and the Global Atmosphere

[61] http://www.airspacemag.com/need-to-know/NEED-lifecycles.html

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