European
Gas
Forum

A Report by the European Gas Forum, September 2012

Reducing CO_2 emissions in the EU Transportation Sector to 2050

An alternative pathway to reach 2050 abatement targets with lower costs

centrica eni e·on Ruhrgas GAZPROM EXPORT GDF SUEZ قطر للبترول Qatar Petroleum Statoil

September 2012

Appendices

Appendix 1: Current and future transport policy and legislation

Appendix 2: Fuel price assumptions

Appendix 3: Alternative technologies

Appendix 4: Baseline scenario – Powertrain mix

Appendix 5: Alternative scenario – Power train mix

Appendix 6: Key scenario input assumptions

Appendix 7: Scenario analysis results – supporting data

Appendix 1: Current and future transport policy and legislation

Current transport policy and legislation

The Transport White Paper presents the European Commission's vision for the future of the EU transport system and defines a policy agenda for the next decade (published early 2011). The programme is part of the Europe 2020 strategy and its flagship initiative for a resource efficient Europe. It defines 10 major targets (see below) designed to guide policy actions and measure progress — including phasing out conventionally fuelled cars from cities by 2050, and a 50 % shift in middle distance passenger and longer distance freight journeys from road to other modes by the same date — to achieve a 60% reduction in CO_2 emissions and comparable reduction in oil dependency. These are underpinned by 40 concrete initiatives — to be developed over this decade. These targets have been set on the basis of the 2050 roadmap, a broader strategy that defines the most cost‑effective ways to reduce GHG emissions based on the outcome from modelling to meet the long‑term target of reducing overall emissions by 80% to 95%. Key targets include:

- Transport GHG emissions (including international aviation, excluding international maritime shipping) reduced by 20 % (versus 2008) by 2030, and reduced by 60% (versus 1990) by 2050;
- EU CO_2 emissions of maritime bunker fuels down 40% (versus 2005) by 2050;
- To achieve a 40% share of low carbon sustainable fuels in aviation by 2050;
- Use of conventionally fuelled cars in urban transport down by 59% in 2030 and by 100% by 2050;
- CO2-free city logistics in major urban centres by 2030;
- Most medium-distance passenger transport covered by rail by 2050;
- Road freight over 300km shift to rail/waterborne transport 30% by 2030 and minimum 50% by 2050;
- 70% reduction of transport oil consumption from today by 2050.

The White Paper is building on 3 major pillars of action: Developing and deploying new and sustainable fuels and propulsion systems; Optimising the performance of multimodal logistic chains, including by making greater use of more energy-efficient modes; and Increasing the efficiency of transport and of infrastructure use with information systems and market-based incentives.

Other prominent legislation and policy in the transport sector aimed at GHG emissions include:

- Passenger Car CO_2 Regulations (443/2009/EC);
- Van CO_2 Regulations (510/2011/EC);
- Fuel Quality Directive (FQD) (2009/30/EC);
- Renewable Energy Directive (RED) (2009/28/EC); and
- IMO Energy Efficiency Design Index (EEDI).

These are discussed in more detail below.

The **Passenger Car CO_2 Regulations** sets a binding target for new cars of 120 g/km phased in over the period 2012 - 2015. It defines an integrated approach focusing on mandatory reductions to reach an objective of 130 g CO_2/ km on average for the new fleet through improvements in vehicle motor technology, and further reduction of 10 g CO_2/km or equivalent, by other complementary measures (for instance, the increased use of biofuels or efficiency improvements for car components with impact on fuel consumption such as tyres and air conditioning systems). The Regulation defines a limit value curve of CO_2 emissions allowed for new vehicles according to the mass of the vehicle. The curve is set in such a way that the fleet average to be achieved by all cars registered in the EU is 130 g/km. A so-called limit value curve implies thus that heavier cars are allowed higher emissions than lighter cars, provided the overall fleet average is preserved. Regulation 443/2009/EC also provides manufacturers with an incentive to reduce the CO_2 emissions of their vehicles by imposing an excess emissions premium. The Regulation indicates that a target of 95 g CO_2/km will be specified for the year 2020. The modalities for reaching this target and the aspects of its implementation including the excess emissions premium will have to be defined in a review to be completed no later than the beginning of 2013[1].

As part of its strategy to cut CO_2 emissions from light-duty vehicles, in May 2011 the EU adopted legislation to reduce emissions from vans ('light commercial vehicles'), similar to that passed in 2009 for passenger cars. The **Vans CO_2 Regulations** aim to cut emissions from vans to an average of 175g CO_2/km by 2017 – with the reduction phased in from 2014 - and to 147g CO_2/km by 2020. These cuts represent reductions of 14% and 28% respectively compared with the 2007 average of 203g CO_2/km. As for passenger cars the obligated entity to which targets apply, and to which penalties would be applied for failure to meet the targets, are the manufacturing groups. Emission limits are set according to the mass of vehicle, using a limit value curve. The curve is set in such a way that a fleet average of **175g of CO_2 per kilometer** is achieved. The limit value curve means that heavier vans are allowed higher emissions than lighter vans while preserving the overall fleet average.

The legislation affects vans, which account for around 12% of the market for light-duty vehicles. This includes vehicles used to carry goods weighing up to 3.5t (vans and car-derived vans, known as "N1") and which weigh less than 2610kg when empty. If the average CO_2 emissions of a manufacturer's fleet exceed its limit value in any year from 2014, the manufacturer has to pay an excess emissions premium for each van registered. A target of **147g CO_2/km** is specified for the year **2020**. This needs to be confirmed in a review of the Vans Regulation, based on an updated assessment of its costs and benefits that is to be completed no later than the beginning of 2013. The modalities for reaching this target and aspects of its implementation, including the excess emissions premium, will also be defined as part of the review[2].

The **Fuel Quality Directive (FQD)** sets a Low Carbon Fuel Standard, a reduction of the greenhouse gas intensity of the fuels by up to 10% by 2020 (for more details see below). The legislation applies to all petrol and diesel used in road transport and gasoil used in non-road-mobile machinery. Suppliers can choose to group together to meet the below targets jointly. The GHG intensity of fuels are required to be calculated on a life-cycle basis, meaning that the emissions from the extraction, processing and distribution of fuels are included. Life-cycle greenhouse gas emission reductions will be calculated from a 2010 baseline of fossil fuel greenhouse gas intensity.

For biofuels to count against the greenhouse gas emission reduction targets they must meet certain sustainability criteria set out in the Directive to minimise the undesired impacts from their production. As with fossil fuels, the greenhouse gas emissions from biofuels should be calculated on a life-cycle basis. Emissions from directly converting land to agricultural use for producing biofuels (direct land use change) must be reported under the current approach. From January 2011 suppliers are required to report annually on GHG intensity of fuel and energy supplied within each MS, including the following as a minimum:

- The total volume of each type of fuel or energy supplied, indicating where purchased and its origin; and
- Lifecycle GHG emissions per unit of energy.

As well as setting targets to reduce the GHG intensity of fuels, the legislation also controls other elements of fuel quality primarily linked to air pollutant emissions. In 2009 the average sulphur content of both types of fuel for use in road vehicles had fallen below 10ppm thanks to the mandatory introduction of sulphur-free fuels under this legislation.

According to the **Renewable Energy Directive (RED)**, Member States need to ensure that the share of renewable energy in the EU final energy consumption reaches at least 20%, and establishes national overall targets for each Member State. Renewable energy consists of three sectors – electricity, heating and cooling, and transport. MS are to retain discretion as to the mix of these sectors in reaching their national target.

---

[1] This review is in progress (AEA are part of the consortium undertaking this). The findings to date suggest it will confirm the published regulation.

[2] This review is in progress (AEA are part of the consortium undertaking this). The findings to date suggest it will confirm the published regulation.

IMO's Marine Environment Protection Committee (MEPC) has developed the **Energy Efficiency Design Index (EEDI)** for new ships (MEPC.1/Circ.681) to create stronger incentives for further improvements in ships' fuel consumption. The purposes of IMO's EEDI are:

- to require a minimum energy efficiency level for new ships;
- to stimulate continued technical development of all the components influencing the fuel efficiency of a ship;
- to separate the technical and design based measures from the operational and commercial measures (they will/may be addressed in other instruments); and
- to enable a comparison of the energy efficiency of individual ships to similar ships of the same size which could have undertaken the same transport work (moved the same cargo).

Ships' CO_2 emissions are directly proportional to its fuel consumption, with, on average, 3.1 tonnes of CO_2 being released from each tonne of fuel burnt. The EEDI will require, in the first phase (2015-2019) an efficiency improvement of 10% and will be tightened every five years, to keep pace with technological development and reduction measures. Through its decision, the IMO has set reduction rates until the period 2025 to 2030 when a 30% reduction in energy consumption is mandated for most ship types calculated from a baseline representing the average efficiency for ships built between 1999 and 2009. The EEDI will become mandatory from 2015. It will be applied to the largest segments of the world merchant fleet, and is expected to cover as much as 70% of emissions from new ships.

Proposed changes legislation and future legislation

A number of changes are planned to legislation in the near future, and there are also plans for new legislation to be developed/introduced. These are summarised below:

Possible amendments to Regulation 443/2009 on Passenger Car CO_2 emissions and 510/2011 on Van CO_2 emissions - Both regulations are currently providing short-term and longer term CO_2 targets up to 2020 for light duty vehicles (vans and passenger cars). A stakeholder meeting organised by the European Commission on 6 December came to the general conclusion that the current targets and metrics are sound until 2020. Factors for changes in the regulation and targets post-2020 are currently being considered, among others a possible change to the test cycle (based on an international standard) and the inclusion of other greenhouse gases in addition to carbon dioxide, though these options are very much preliminary.

Possible Heavy Duty Vehicle regulations on CO_2 - For Heavy Duty Vehicles there is at present no EU regulation of their greenhouse gas emissions and the Commission intends to put forward a strategy for addressing these. AEA was recently assigned by the European Commission to assess different pathways for the reduction and testing of greenhouse gas (GHG) emissions from heavy duty vehicles. The 2011 assessment concluded that there are a number of policy instruments that have the potential to deliver significant CO_2 reductions from heavy duty vehicles, and which can be implemented at the European level. The following short-list of policy instruments to be assessed and developed further was identified:

- Emissions trading scheme, either a stand-alone scheme or integration into the EU ETS;
- Performance requirements for vehicles, their combinations and their components;
- Labelling of vehicles, combinations or components;
- Programme to disseminate best practice;
- Reduction in speed for heavy duty vehicles;
- Changes to weights and dimensions legislation, including the possibility of allowing longer vehicles without allowing for increases in capacity;
- Driver training;
- Fuel taxes;
- Road user charges;
- Differentiated vehicle purchase taxes or incentives.

These measures are currently elaborated by the European Commission. In addition to the strategic review of options to regulate CO_2 from heavy duty vehicles (known as the Heavy duty Vehicle Lot 1 project), a sister project (Lot 2) is currently underway to consider the options and practicalities of developing a CO2 test. This project is led by the Technical University at Graz, and is in progress[3]

EU action to control emissions from maritime transport - The European Union is actively engaged in pursuing international agreement on global measures to reduce greenhouse gas emissions from international maritime transport. Although considerable efforts are being made, primarily in the International Maritime Organization (IMO) and the United Nations Framework Convention on Climate Change (UNFCCC), progress towards effective global reduction measures has so far been limited.

In parallel, if the IMO and UNFCCC processes fail to include emissions from shipping into reduction commitments this year, there is a commitment from the EU to include these emissions into the existing EU reduction commitment. In this regard, the European Commission is considering possible European action in 2012.

Directive 2009/29/EC and Decision 406/2009/EC and of the European Parliament and of the Council of 23 April 2009 call on the Commission to come forward with a proposal to include international maritime GHG emissions in the Communities reduction commitment if there is no successful conclusion in the international negotiations in the International Maritime Organisation and/or the United Nations Framework Convention on Climate Change[4].

IMO conventional pollutant emissions limits for shipping and Environmental Control Areas (ECAs) - In October 2008, IMO adopted the Revised MARPOL Annex VI and the NOX Technical Code 2008, which entered into force on 1 July 2010. The main changes are a progressive reduction in emissions of SOX, NOX and particulate matter and the **extension of designated emission control areas (ECAs)** for more stringent control of the emission of SOX to NOX and particulate matter (PM) as well.

Under MARPOL Annex VI, the global sulphur cap for fuel oil used on-board ships is reduced initially to 3.50%m/m (from the current 4.50%), effective from 1 January 2012; then progressively to 0.50%, effective from 1 January 2020, subject to a feasibility review to be completed no later than 2018. The sulphur limits for fuel oil applicable in ECAs for SOX and particulate matter are 1.00%, and further reduced to 0.10%, effective from 1 January 2015.

Progressive reductions in NOX emissions from marine diesel engines are also included, with more stringent controls being a “Tier II” emission limit required for those marine diesel engines installed on or after 1 January 2011; then with the most stringent controls being “Tier III” emission limit for marine diesel engines installed on or after 1 January 2016, that are used on ships operating in ECAs designated for controlling NOX. Marine diesel engines installed on or after 1 January 1990 but prior to 1 January 2000 are also required to comply with “Tier I” emission limits, if an approved method for that engine has been certified by an Administration.

The first such ECA covers the Baltic and North Seas – SO2 and particulate emission restrictions being in effect from 2015, and NOX in 2016. It is anticipated that other areas receiving implementation dates and targets are likely to include Mediterranean, Southeast Asia, Northeast Asia and North America[5].

Other possible IMO market-based measures - Technical and operational measures will not be sufficient to satisfactorily reduce the amount of GHG emissions from international shipping in view of the growth projections of human population and world trade. Therefore, Market-Based Measures are also being considered and would serve two main purposes:

- providing a fiscal incentive for the maritime industry to invest in more fuel efficient ships and more sophisticated technologies and
- to operate ships in a more energy efficient manner and off-setting of growing ship emissions.

- In 2010, the MEPC conducted a feasibility study and impact assessment of market-based measures to reduce GHG from maritime transport. There are eight types of mechanism currently being assessed:

---

[3] http://ec.europa.eu/clima/policies/transport/vehicles/docs/ec_hdv_ghg_strategy_en.pdf

[4] http://ec.europa.eu/clima/policies/transport/shipping/index_en.htm

[5] http://www.imo.org/OurWork/Environment/Documents/IMO%20and%20the%20Environment%202011.pdf

- An International Fund for Greenhouse Gas emissions from ships (GHG Fund)
- Consolidated proposal of the Efficiency Incentive Scheme (EIS) based on the Leverage Incentive Scheme (LIS) and the Vessel Efficiency System (VES)
- Port State arrangements utilizing the ship traffic, energy and environment model, STEEM (PSL)
- Ship Efficiency and Credit Trading (SECT)
- Global Emission Trading System (ETS)
- How technical and operational measures are the only direct and effective means to deliver cuts in CO_2 emissions
- A Rebate Mechanism (RM) for a market-based instrument for international shipping[6]

---

[6] http://www.imo.org/OurWork/Environment/Documents/IMO%20and%20the%20Environment%202011.pdf

Appendix 2: Fuel price assumptions

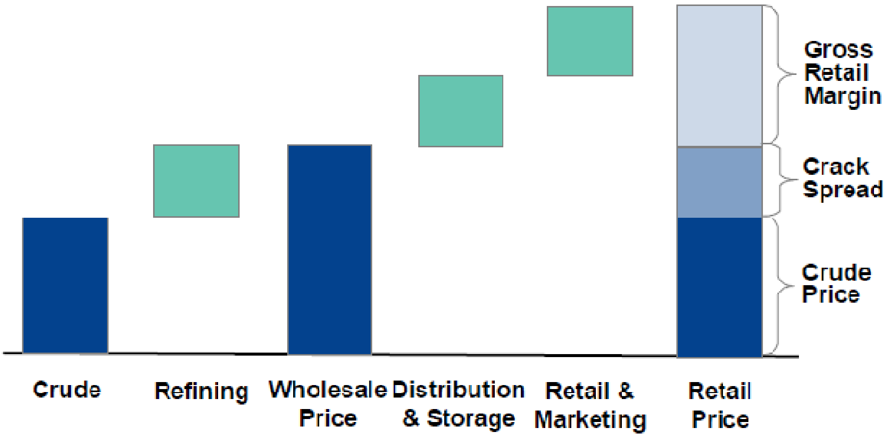
This appendix explains in detail the fuel price projections that have been used by AEA in the scenario analysis, and how these were derived.

Methodology

The input required by the analysis is the pre-tax retail price for each of the transport fuels. The European Commission's oil and natural gas projections to 2050 (both their Current Policy Initiatives and Low Fossil Fuel Price scenarios) have been used as the basis for the projections, to be as consistent as possible with EGaF analysis for other sectors and with other Commission work.

In order to derive a pre-tax retail price from crude oil and natural gas prices, the total gross margin added to cover the cost of converting the feedstock fuel into the final product, and bringing this product to market needs to be estimated. This margin is outlined below in Figure A2.1. This margin has been estimated for 2010 as the difference between known pre-tax retail fuel prices and the Commission's 2010 crude oil and natural gas prices.

Figure A2.1 – components of pre-tax retail price for oil-derived transport fuels[7]



A simplified method for projecting these prices forward using the Commission oil and natural gas projections was required. Two simple methods are:

- To assume that the total gross margin is fixed, and that the only variable component of the final fuel price is the crude oil or natural gas price;
- To assume that the total gross margin is a fixed percentage of the crude oil or natural gas price.

Analysis performed by Poyry[7] on historical data suggests that in reality, both would be a simplification of a market that is much more complex in practice, with variation by fuel and region. However, given the significant uncertainty in even crude prices to 2050, this simplification was deemed appropriate for this study. Therefore, it has been assumed that a small proportion (10%) of the margin varies in proportion to the crude oil/gas price, whilst the remaining 90% stays constant through the entire time period.

2010 prices

Known 2010 prices are required for the methodology outlined above. For gasoline and diesel, reliable, self-consistent data are available. However, this is not the case for many of the transport fuels considered. Figure 3 below outlines the data sources, and values used, for each of the main transport fuels used in the scenario analysis. Note that infrastructure is included in the fuel price – where this is not already the case, the cost of infrastructure has been estimated and added to the price.

As can be seen, the price estimates are from a variety of sources and it is difficult to assess how consistent these are with one another. Further complications are presented for natural gas transport fuels, where there is less

---

[7] Source: Poyry (2009), SURVEY OF THE COMPETITIVE ASPECTS OF OIL AND OIL PRODUCT MARKETS IN THE EU, http://ec.europa.eu/energy/oil/studies/doc/2009_oil_market_survey.pdf

competition and transparency compared with gasoline and diesel, where the market is far less developed, and where price can vary strongly with local conditions (e.g. country, region, access to infrastructure). Figure A2.2 below shows the fuel prices used graphically.

Figure A2.2 – 2010 fuel prices used (€2010/MJ gross, pre-tax retail including refuelling infrastructure)

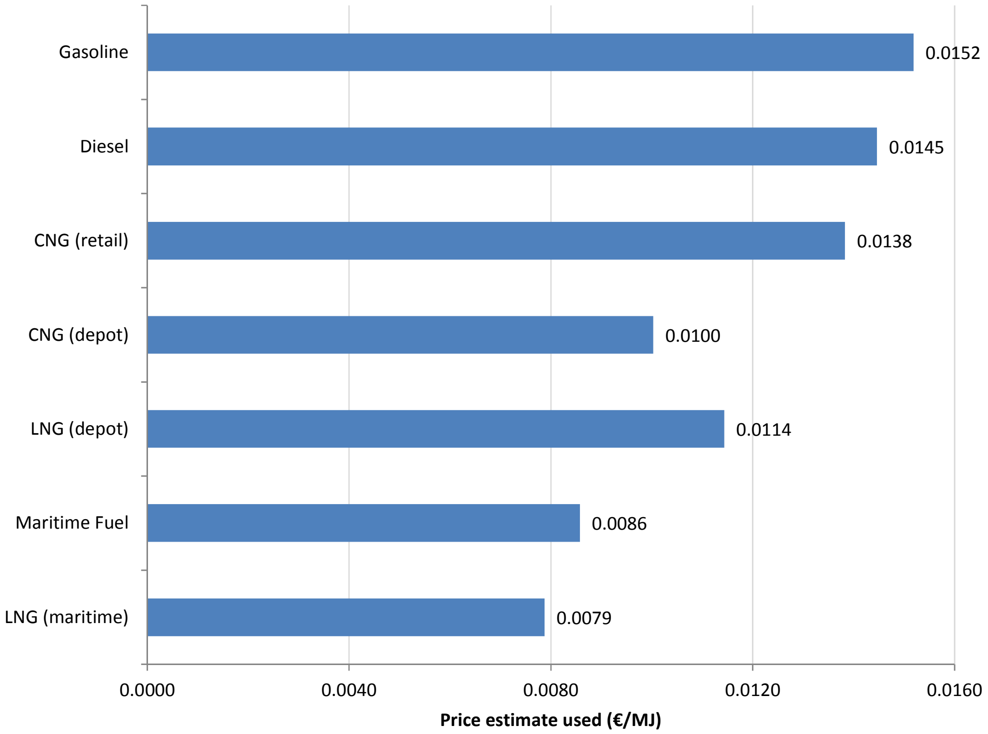


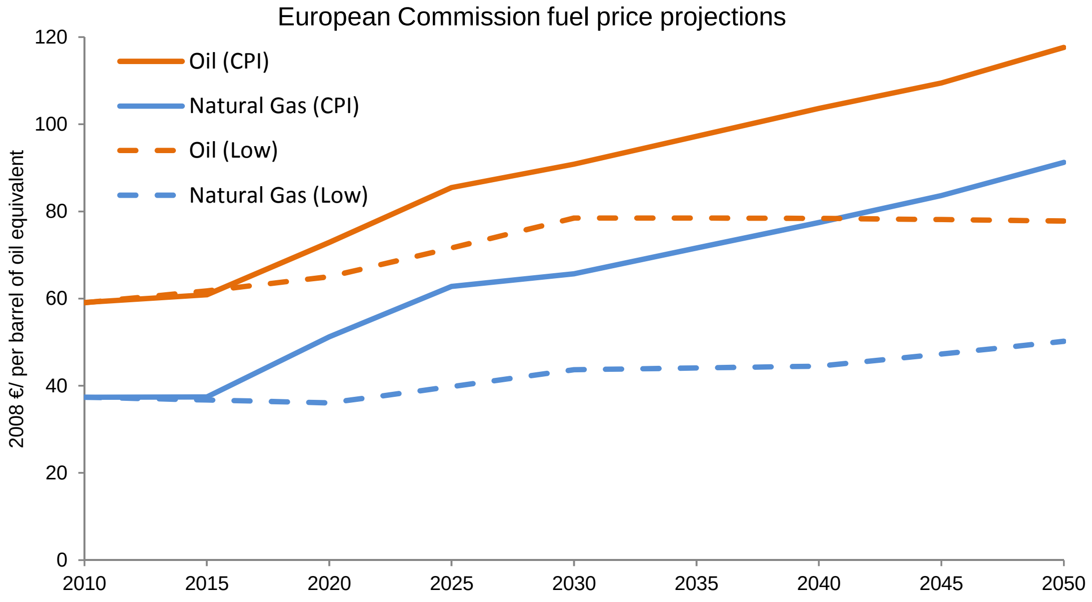
Figure A2.3 – data and sources for 2010 price estimates

Fuel	**2010 price estimate (pre-tax)**	**Original unit**	**Source**	**Conversion**	**Conversion factor**	**Uplift for refuelling infrastructure (€/MJ)**	**Source**	**Price estimate used (€/MJ)**
Gasoline	525.12	€/1000L	DG Energy Oil Bulletin, EU consumption weighted average	MJ/100L (gross)	34579	Included in price	-	**0.0152**
Diesel	551.76	€/1000L	DG Energy Oil Bulletin, EU consumption weighted average	MJ/100L (gross)	38148	Included in price	-	**0.0145**
CNG (retail)	0.5359	€/Nm3	NGVA European gas pricing comparisons 2010, EU consumption weighted average, duty and VAT removed	MJ/Nm3 (gross at density of 0.73 kg/m3)	38.76	Included in price	-	**0.0138**
CNG (depot)	0.36	€/Nm3	Average of indicative range (0.35-0.37)	MJ/Nm3 (gross at density of 0.73 kg/m3)	38.76	0.00074	AEA estimate based on quoted figures for Madrid CNG bus fleet depot	**0.0100**
LNG (depot)	16.16	$/MMBtu	Presentation 'Innovative uses of LNG in the transportation sector, Sergei Komlev, Gazprom Export, June 2011 (indicative for Netherlands)	MJ/MMBtu (1055.056), €/$ (0.698)	1511.0	0.00074	AEA estimate: same as CNG fleet refuelling infrastructure costs	**0.0114**
Maritime Fuel	0.0086	€/MJ	2011 European average back calculated to 2010 (Platts.com)	-	-	Included in price	None, but uplift added for desulphurisation (25% in 2015, 50% from 2020 onwards)	**0.0086**
LNG (maritime)	0.0064	€/MJ	EC projection for raw gas price - assuming LNG price at hub tracks gas price (assumption used in North European LNG Infrastructure Project)	-	-	0.00145	Calculation based on North European LNG Infrastructure Project Appendix B (Terminal Cost analysis)	**0.0079**

European Commission crude oil and natural gas projections

The fuel prices have been projected based on the European Commission crude oil and natural gas projections used in the recent Energy Road Map. The ‘Current Policy Initiatives’ projection has been used for the high fossil fuel price scenario, and the ‘Low fossil fuel price’ projection for the low fossil fuel price scenario. These fuel prices are shown below in Figure A2.4. It can be seen that in the ‘CPI’ case, the spread between crude and natural gas stays broadly constant throughout the time series (although in 2015 and 2030 the spread increases slightly as natural gas prices grow more slowly than crude oil prices). In the ‘Low’ case, the spread increases to 2030 and then declines to 2050.

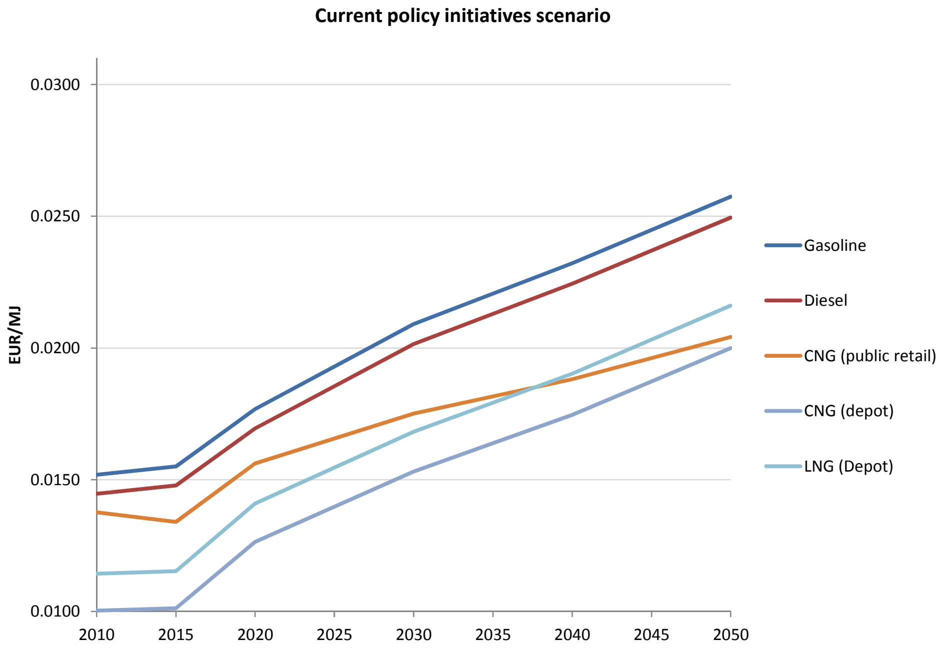
Figure A2.4 – European Commission fuel price projections used



Resulting fuel price projections

Fuel prices are projected from the 2010 values as described in the methodological section above. These are shown below for both the ‘Current policy initiatives’ (high price) and ‘low fossil fuel prices’ (low price) scenarios.

Figure A2.5 – Fuel price projections for road transport fuels under both price scenarios



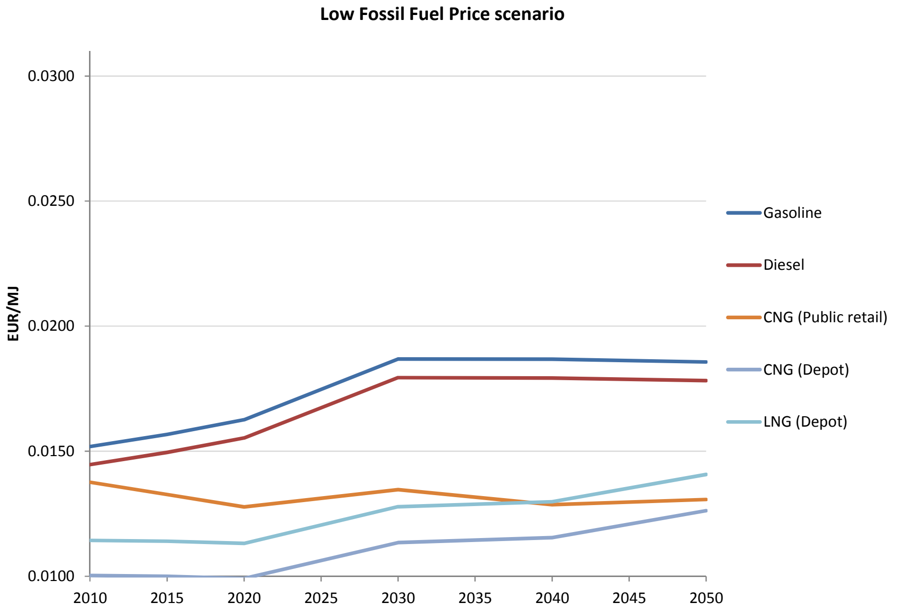
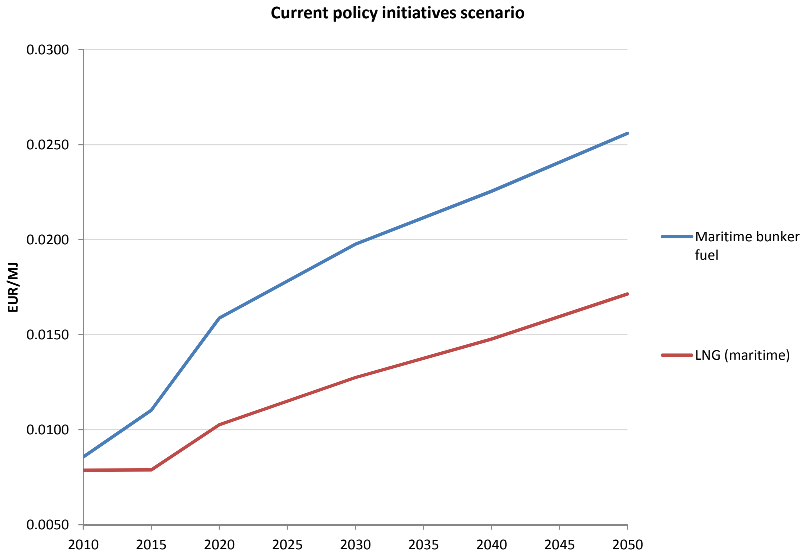
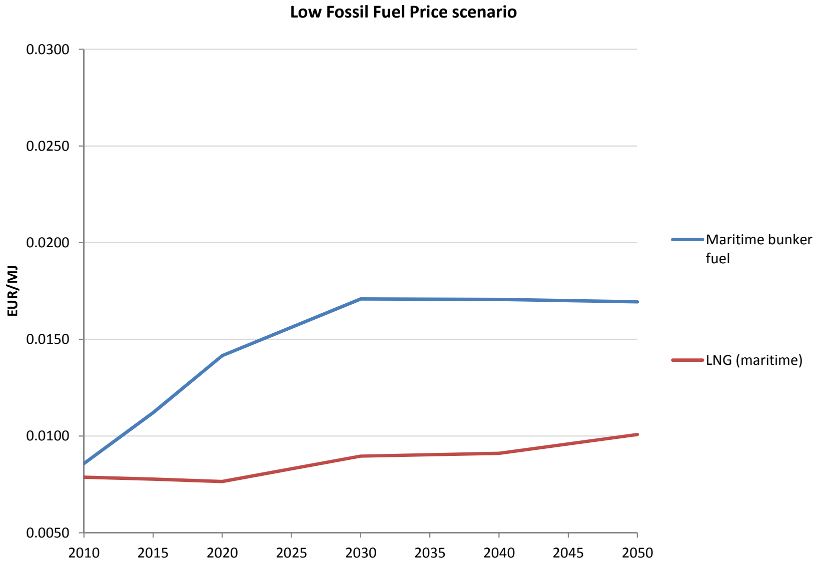


Figure A2.6 – Fuel price projections for maritime transport fuels under both price scenarios


Current policy initiatives scenario


Low Fossil Fuel Price scenario

Notes on fuel price projections

CNG retail and CNG/LNG depot

Currently, retail CNG has a significantly higher gross margin than gasoline and diesel in many countries. This can be observed in the data obtained, where the CNG retail price is only slightly lower than the gasoline and diesel prices despite the basic natural gas price being significantly lower than crude oil. It is understood that much of this gross margin is likely to be at the retail side, where retailers need to regain their investment in CNG refuelling infrastructure that is not as heavily used as gasoline/diesel refuelling infrastructure, because there are less CNG vehicles on the road. However, the data suggests that fleet operators would negotiate CNG (or LNG) supply prices that would be lower than the current retail price – effectively a similar price paid by industrial users plus the cost of refuelling infrastructure. Therefore, there are separate CNG and LNG prices for this business model, to account for the fact that fleet operators are likely to have access to much lower fuel prices.

CNG retail's declining margin

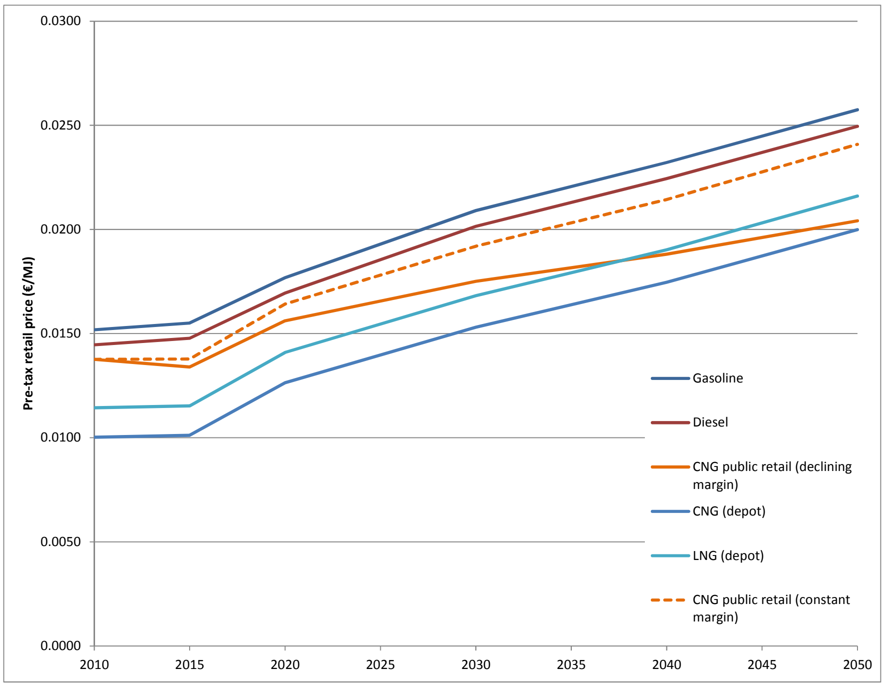
In the projections used in this study, the retail price for CNG does not track the same trajectory as the other fuels (i.e. the crude oil/natural gas projection trajectory). This is because of the assumption that the gross margin is declining from its initial value in 2010 to a final value in 2050 that is the same as the gross margin on diesel fuel. This assumption is made because, as outlined above, the current CNG margin is high and this is expected to decline as the market develops. This would occur because of a number of factors, including increased competitiveness, increased utilisation of infrastructure, and infrastructure investments paying back.

The outcome of this assumption, as seen in Figure 7, is that the spread between the price of public retail CNG and gasoline/diesel increases throughout the time period. In 2050, the price for public retail CNG is approaching the price for depot CNG. This would be expected as a very competitive public retail CNG refuelling station running at a lower gross margin would start to approach 'wholesale + infrastructure' prices.

LNG (depot) prices

The data obtained for 2010 indicate that LNG is on average more expensive than CNG on a wholesale basis. However, the data are from very different sources and may not be consistent – we are aware that prices for both are highly variable. Since both are projected on the same basis, this spread in price is maintained throughout the time period.

Figure A2.7 – fuel price projections for road transport fuels (high price scenario) showing the projected price of retail CNG at a fixed and declining margin



Appendix 3: Alternative technologies

Road transport [8] [9]

Technology	Description	CO_2 reduction potential
Battery Electric Vehicles (BEV)	BEVs utilise an electric motor powered by a series of batteries to propel the vehicle, with grid electricity and regenerative braking charging the batteries. The potential CO_2 saving of this technology will depend on the carbon intensity of the grid electricity and on the driving cycle. 100% CO_2 saving is possible if electricity from renewable sources is used and around 40% CO_2 saving is achievable with today's grid carbon intensity,	<40%
Hybrid Vehicle	A hybrid powertrain uses energy from multiple sources, of which at least one is reversible. The most common variant is an internal combustion engine combined with a battery and an electric motor. This battery is charged during braking and discharged during acceleration. The size of the battery will determine the distance the vehicle can travel on electrical energy.	10- 25%
Downsizing with turbocharging	By decreasing the volume of an engine while inserting a two-stage turbocharger, the same peak power output is possible. This reduces fuel consumption as the smaller engine has reduced pumping losses, less heat transfer and frictional losses.	10- 20%
Variable compression ratio	Using a variable compression ratio allows the compression ratio within an engine to dynamically match variations in the required power output. This optimises the energy transfer during different engine load levels, increasing the engine efficiency.	10%
Start/Stop	This system uses a high-voltage electric motor mounted to the crankshaft to stop the engine when the vehicle is stationary and instantly restart it when power is required. The electric motor is only utilised to start the engine and does not propel the vehicle.	5-10%
Direct injection	Direct injection in gasoline engines allows better control of the amount and timing of the fuel inlet in the combustion chamber. The fuel mixture is more evenly dispersed which allows for a more aggressive timing of the combustion, increasing engine efficiency.	3 – 10%
Cylinder deactivation	Cylinder deactivation is the temporary reduction of an engine's capacity at low loads by only using some of the available cylinders. Because of its reduced capacity the engine will, even at low loads, operate close to its full capacity and hence more efficient.	5- 8%
Variable valve control	This encompasses a series of technologies that allow continuous control over the valve actuation. Besides variable valve timing, it includes technologies that enable control over the amount of lift of the valves, which implies control over the duration of the valve's opening and closing.	7%
Dual clutch	A dual-clutch transmission is essentially a system of two transmissions operating in parallel. It is set up in such a way that one set of gears is always remains engaged during gear shifting. This allows continuous power to the transmission, avoiding deceleration and subsequent acceleration during gear changes.	5%

---

[8] AEA Technology, 2009, EU Transport GHG: Routes to 2050? Technical Options to reduce GHG for non- Road Transport Modes (Paper 1). Available online at: http://www.eutransportghg2050.eu

[9] AEA et al (2008) Impacts of regulatory options to reduce CO2 emissions from cars, in particular on car manufacturers, Report to the European Commission: http://ec.europa.eu/clima/policies/transport/vehicles/docs/2008_co2_car_en.pdf

Technology	Description	CO_2 reduction potential
Weight reduction	Weight reductions can be achieved by replacing some of the steel with materials such as aluminium, glass fibre or carbon fibre composites. The CO_2 saving will depend on the weight reduction, but If the power-to-weight ratio remains constant, then a 10% reduction in vehicle weight equates to a 6.5% reduction in CO_2 emissions.	6.5% per 10% weight loss
Low Rolling Resistance Tyres	Low rolling resistance tyres are designed to minimise the rolling resistance whilst still maintaining the required levels of grip. This reduces the wasted energy of the vehicle, and the greatest CO_2 saving will come on long haul or motorway journeys. This CO_2 saving will decrease as the tyres wear out.	3- 5%

Maintime technologies[10] [11]

Technology	**Description**	**CO_2 reduction potential**
Diesel electric drives	Substituting coupled electric drives for the traditional direct engine-propeller shaft connection can deliver substantial savings, especially where frequent changes in shaft load and operating profiles are required (e.g. with frequent manoeuvring).	5 - 30%
Wind power: Flettner rotor	A Flettner rotor is a spinning vertical rotor that converts wind power into propulsive energy. This set-up harnesses wind power irrespective of its direction and can considerably reduce fossil fuel use. However, it requires free deck space for rotor placement.	<30%
Wind Power: Kites and Sails	Traditional sail configurations with advanced fabric, composite materials and/or kites attached to the bow can harness wind power for forward propulsion. Sails and kites can greatly reduce primary power requirements but can experience variable performance depending on wind speed and direction (kites, however, can better exploit constant speed winds at altitude). Sails also require available deck space.	<20%
Bulbous bow	A bulbous below-the-waterline extension of the bow of the ship can improve water flow around the hull and reduce drag for large vessels operating within commercial speed ranges.	<20%
Air lubrification	A recess formed over the length of a vessel's hull into which compressed air can be pumped effectively reduces frictional resistance by "lubrifying" the hull-water contact area. Despite requiring some auxiliary pumping power, this design strategy can reduce fuel use by up to 15% for large surfaced hulls on slower-speed vessels (e.g. tankers). Fuel savings for container vessels and car carriers are about half as much.	<15%

---

[10] International Transport Forum, 2009, Greenhouse gas emissions reduction potential from international shipping. Available online at: http://www.internationaltransportforum.org/jtrc/discussionpapers/DP200911.pdf

[11] Wartsila, 2009, Boosting Energy Efficiency, available online at: http://www.scheepsemissies.nl/images/files/Wartsila%20Energyefficiency%20Presentation19sep08.pdf

Technology	Description	CO_2 reduction potential
Counter-rotating propellers	Counter rotating propellers consist of a propeller couple behind each other that rotate in opposite directions. The rear propeller recovers some of the rotational energy in the slipstream from the forward propeller.	<12%
Wing thrusters	Combining twin wing thruster propellers to a single shaft main propeller results in fuel savings compared to a twin-shaft design. Energy savings stem principally from reduced friction from the smaller thrusters pods.	<10%
Waste heat recovery	Capturing and re-converting engine exhaust gas heat into electric energy can reduce direct engine fuel requirements for electric-coupled propulsion systems or reduce auxiliary engine requirements. Recovered heat can also be used for other shipboard functions (e.g. fuel heating).	<10%
Pulling Thruster	Combining thrusters with a pulling propeller (e.g. a forward-facing propeller) in either a counter-rotating centre-line setup or as wing thrusters can reduce fuel use for vessels requiring frequent operation at variable loads.	<10%
Propeller surface maintenance	Wet cleaning and polishing propeller surfaces to reduce roughness and the accretion of organic materials can significantly reduce propeller resistance and improve fuel efficiency. This can be accomplished without removing the vessel from its commercial duties.	<10%
Optimum hull dimension	Optimising hull length and fullness for reduced frictional resistance can have a significant impact on fuel consumption. Too large a length to breadth ratio increases wetted surface and frictional resistance while too large a breadth to length ratio leads to increased residual resistance. Designing a typical product tanker to be 10-15% longer can reduce engine demand by ~10% for a constant speed. However, this is an expensive option as increased length increases vessel newbuild costs.	<9%
Design for reduced ballast operation	Designing a vessel to operate with less ballast can represent an important efficiency gain. Lighter displacement means lower wetted hull surface and results in lower resistance. Ballast must be sufficient to preserve stability, handling (e.g. to avoid hull slamming) and immersion of the propeller at optimum depth.	<7%
Lightweight Construction	Replacement of steel by lighter weight alternatives in non-structural elements can lead to fuel efficiency gains. Replacing steel with lower weight high tensile steel can also reduce fuel consumption. Both of these strategies come with relatively significant cost and care must be taken to balance direct CO_2 reductions linked to reduced fuel consumption to the higher CO_2 intensity of mining and smelting lighter weight alternatives. For indicative purposes; a 20% reduction of steel weight will result in approximately 9% lower power requirements for a given vessel configuration and service speed.	<7%

Technology	Description	CO_2 reduction potential
Coatings and Hull Maintenance Strategies	The use of alternative/improved coatings and maintenance of hulls can result in the reduction of frictional resistance, which is a contributor to total resistance, particularly at low speeds.	<5%

Aviation technologies[12]

Technology	Description	CO_2 reduction potential
Unducted fan engine (UDF) or Propfan	The unducted fan or propfan engine is a hybrid between a turbofan and a turboprop. The engine uses a turbofan engine with curved blades relocated to the outside of the engine housing. As the exhaust from the turbofan engine is forced out, the gases pass over a turbine connected to two sets of propellers on the exterior of the engine nacelle. This can give the speed and performance of a turbofan, with the fuel economy of a turboprop.	15 – 30%
Blended wing body (BWB)	BWB is an aircraft that has a flattened, airfoil shaped body with separate wing structures smoothly blended to the body. This is compared to flying wings, which are defined as having no separate body. With this design, the whole aircraft contributes significantly to lift generation, which results in higher aerodynamic efficiency and reduced fuel consumption.	20%
Laminar Flow control	Laminar flow technologies on the upper and lower wing surfaces will result in a reduction in drag by preventing a turbulent flow over the wing. There are two ways to achieve this laminar flow control, passive and active. Passive control involves designing the surface such that the pressure decreases in the flow direction. Active control involves the use of suction or surface cooling to maintain laminar flow.	10- 20%
Lighter composite materials	High temperature Carbon composites are to be used for engine applications, allowing higher operating temperatures, greater efficiency, reduced fuel consumption and reduced weight. Inter-Metallic Composites could also be used in cold end compressor sections, leading to as much as 50% reduction in weight of the affected components. Lightweight materials such as Carbon fibre reinforced plastic (CRFP) and aluminium-fibreglass (Glare) can replace aluminium within the fuselage.	10- 20%
Active airframe health monitoring	This system uses on a network of sensors and actuators to be integrated with the airframe. A diagnostic capability for detecting aircraft damage will predict the residual life of the damaged structures in service. Health monitoring will allow realization of weight reductions that are possible in aircraft design for both metallic and carbon fibre structures.	12%
Geared Turbofan (GTF)	The geared turbofan uses a gearbox instead of a low-pressure turbine to power a fan within the engine. This allows the fan, low-pressure compressor, and turbine to operate at different speeds. Hence, the gearbox allows for a more efficient regulation of fan speed which results in increased engine efficiency.	8-10%
Morphing structure and control	The concept of morphing is where an aircraft is able to change shape during flight e.g. a wing is able to adapt itself for different aerodynamic characteristics, optimising aerodynamic control, reducing drag and hence increasing efficiency. Smart materials, such as shape memory alloys are integral to this concept.	5%

---

[12] Qinetiq, 2008, Aviation CO_2 Emissions Abatement Potential from Technology Innovation 2008. Available online at: http://www.theccc.org.uk/pdfs/QinetiQ%20aviation%20report%20for%20the%20CCC.pdf

Technology	Description	CO_2 reduction potential
New engine technologies: higher OPR, better materials & cooling	Evolution of engine technologies such as a higher overall pressure ratio (OPR) will allow more heat to be converted into jet speed, improving the specific fuel consumption. Improvements in engine materials and cooling will enable higher hot end temperature, therefore increasing the turbine efficiency.	3-5%
Aerodynamics of compressor and turbine	Further aerodynamic improvements in the front-end engine intake and nacelle will reduce drag, and advances in the design of the rotating components such as compressor blades will improve the propulsion efficiency, minimising parasitic losses.	3-5%
Unmanned aircraft	The use of unmanned aircraft is already commonplace in the military but is banned for commercial aircraft. Utilising computers to control the aircraft, efficiency gains can be achieved by optimizing engine control during flight and improving aircraft trajectories to reduce fuel consumption.	2-3 %
Riblets	Riblets are tiny grooves on the surface of an aircraft that reduce the skin friction drag from turbulent airflow. These riblets can be embedded in the aircraft paint by stamping a riblet pattern into the lacquer paint when it is applied.	1-2%

Rail technologies[13 14]

Technology	Description	CO_2 reduction potential
Electrification	Electrification is the replacement of diesel locomotives with electric motors powered by grid electricity. This is a mature and proven technology, but currently only around 51% of European tracks are electrified. The CO_2 saving of this technology will depend on the carbon intensity of the electricity, and with the UK mix, this would equate to between 20 to 40% reduction in CO_2 emissions.	20 - 40%
Regenerative braking – AC network	Regenerative braking is an energy recovery mechanism which converts the kinetic energy of the train into electricity. Here the electric motor used to propel the train is changed into an alternator and electricity is produced as the train decelerates. This electricity can then be fed into the grid or stored via an on-board battery.	10 - 15%
Double deck trains	Utilising a railcar with two levels of passenger seating can increase the seating capacity per train length by around 20-40%. This leads to a decrease in per passenger fuel consumption. However, it can be difficult to retrofit double deck trains on existing lines as tunnels, bridges, and stations need to be upgraded.	>10%
Wide body trains	A 10 to 20% increase in carriage body width will allow for the accommodation of another seat per row in the passenger deck. This will allow two 3-seating arrangements in second class and two 2-seating in first class, decreasing per passenger fuel consumption.	>10%
Bogie fairings	Bogie (wheel chassis) and wheels contribute to 45% of the aerodynamic drag of a train. Streamlining and smoothing these with the addition of aerodynamic fairings can reduce the drag of train by 10% and hence decrease power requirements for propulsion.	6 – 7%
Articulated trains (Jacobs bogies)	Conventional stock consists of individual carriages resting on two bogies (wheeled chassis), whereas in articulated trains, consecutive cars rest on one shared bogie connecting the two cars. This reduces the mass of the train carriage and hence reduces fuel consumption.	2 – 5%
Lightweight coach interior equipment	Interior passenger equipment accounts for 10-20% of the total coach weight. New construction techniques such as pre-impregnated composite fibres with a foam honeycomb core can produce weight savings of interior fittings of around 35%.	2 – 5%
Improved air conditioning	Air conditioning compromises 20% of the energy consumption of the train and advanced air conditioning measures can reduce this by around 25%. These include CO_2 based demand control (which varies the rate of cooling or heating according to an estimate of the number of people in each carriage, based on the CO_2 they exhale), and using waste heat from traction equipment to heat the carriages.	4%

---

[13] AEA Technology, 2009, EU Transport GHG: Routes to 2050? Technical Options to reduce GHG for non-Road Transport Modes (Paper 3). Available online at: http://www.eutransportghg2050.eu/cms/assets/EU-Transport-GHG-2050-Paper-3-Technical-options-for-non-road-modes-30-10-09-FINAL.pdf

[14] Energy efficiency technologies for railways., Available online at: http://www.railway-energy.org/

Appendix 4: Baseline scenario – Powertrain mix

Split of new vehicle sales by powertrain – Baseline scenario

Passenger car

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	50.2%	54.3%	55.2%	40.1%	25.0%	15.0%	5.0%	2.5%	0.0%
Diesel	42.8%	39.4%	36.3%	30.7%	25.0%	15.0%	5.0%	2.5%	0.0%
HEV gasoline	0.2%	0.8%	2.6%	7.3%	12.0%	16.0%	20.0%	17.5%	15.0%
HEV diesel	0.2%	0.5%	1.7%	6.8%	12.0%	16.0%	20.0%	17.5%	15.0%
PHEV gasoline	0.0%	0.0%	0.0%	4.0%	8.0%	11.5%	15.0%	16.5%	18.0%
PHEV diesel	0.0%	0.0%	0.0%	4.0%	8.0%	11.5%	15.0%	16.5%	18.0%
EV	0.0%	0.0%	0.0%	2.5%	5.0%	7.5%	10.0%	12.5%	15.0%
FCEV	0.0%	0.0%	0.0%	1.0%	2.0%	4.5%	7.0%	11.0%	15.0%
LPG	5.9%	4.4%	3.7%	2.3%	1.0%	0.5%	0.0%	0.0%	0.0%
CNG	0.7%	0.6%	0.6%	1.3%	2.0%	2.5%	3.0%	3.5%	4.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Vans

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	36.3%	38.0%	38.4%	26.7%	15.0%	11.0%	7.0%	4.5%	2.0%
Diesel	63.4%	60.2%	56.3%	49.1%	42.0%	31.0%	20.0%	14.0%	8.0%
HEV gasoline	0.2%	0.8%	2.2%	5.1%	8.0%	8.0%	8.0%	6.5%	5.0%
HEV diesel	0.2%	1.0%	3.0%	9.0%	15.0%	17.5%	20.0%	17.5%	15.0%
PHEV gasoline	0.0%	0.0%	0.1%	2.5%	5.0%	7.5%	10.0%	10.0%	10.0%
PHEV diesel	0.0%	0.0%	0.1%	4.1%	8.0%	14.0%	20.0%	25.0%	30.0%
EV	0.0%	0.0%	0.0%	2.5%	5.0%	7.5%	10.0%	15.0%	20.0%
FCEV	0.0%	0.0%	0.0%	1.0%	2.0%	3.5%	5.0%	7.5%	10.0%
LPG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Medium trucks

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	99.7%	99.1%	93.0%	71.5%	50.0%	37.0%	24.0%	12.5%	1.0%
HEV diesel	0.3%	0.9%	5.0%	15.0%	25.0%	25.0%	25.0%	27.5%	30.0%
PHEV diesel	0.0%	0.0%	1.0%	6.5%	12.0%	18.5%	25.0%	25.0%	25.0%
EV	0.0%	0.0%	0.0%	4.0%	8.0%	11.5%	15.0%	20.0%	25.0%
FCEV	0.0%	0.0%	0.0%	1.5%	3.0%	5.5%	8.0%	11.5%	15.0%
CNG	0.0%	0.0%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Heavy trucks

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	100.0%	100.0%	95.0%	83.5%	72.0%	54.0%	36.0%	20.5%	5.0%
HEV diesel	0.0%	0.0%	5.0%	12.5%	20.0%	32.5%	45.0%	52.5%	60.0%
FCEV	0.0%	0.0%	0.0%	2.5%	5.0%	10.0%	15.0%	22.5%	30.0%
CNG	0.0%	0.0%	0.0%	1.5%	3.0%	3.5%	4.0%	4.5%	5.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Buses

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	98.1%	94.0%	53.5%	36.7%	20.0%	12.5%	5.0%	2.5%	0.0%
HEV diesel	0.2%	5.0%	40.0%	45.0%	50.0%	47.5%	45.0%	40.5%	36.0%
EV	0.0%	0.0%	5.0%	10.0%	15.0%	20.0%	25.0%	28.5%	32.0%
FCEV	0.0%	0.0%	1.0%	8.0%	15.0%	20.0%	25.0%	28.5%	32.0%
CNG	1.7%	1.0%	0.5%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Inland Shipping

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	100.0%	100.0%	98.0%	97.0%	96.0%	94.5%	93.0%	91.5%	90.0%
LNG	0.0%	0.0%	2.0%	3.0%	4.0%	5.5%	7.0%	8.5%	10.0%

Maritime Shipping

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional	100.0%	100.0%	96.0%	93.5%	91.0%	86.0%	81.0%	75.5%	70.0%
LNG	0.0%	0.0%	2.0%	3.0%	4.0%	5.5%	7.0%	8.5%	10.0%
Conv. + Wind	0.0%	0.0%	2.0%	3.5%	5.0%	8.5%	12.0%	16.0%	20.0%
LNG + Wind	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Split of total vehicle stock by powertrain – Baseline scenario

Passenger car

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	60.2%	57.1%	55.8%	51.9%	43.6%	33.2%	22.5%	13.7%	7.6%
Diesel	35.7%	37.8%	38.0%	36.2%	32.6%	27.0%	19.5%	12.4%	7.0%
HEV gasoline	0.1%	0.3%	0.9%	2.6%	5.7%	9.4%	13.3%	15.9%	16.4%
HEV diesel	0.1%	0.2%	0.6%	2.2%	5.3%	9.2%	13.2%	15.8%	16.4%
PHEV gasoline	0.0%	0.0%	0.0%	0.9%	3.1%	6.0%	9.3%	12.3%	14.6%
PHEV diesel	0.0%	0.0%	0.0%	0.9%	3.1%	6.0%	9.3%	12.3%	14.6%
EV	0.0%	0.0%	0.0%	0.6%	1.9%	3.8%	6.0%	8.4%	10.8%
FCEV	0.0%	0.0%	0.0%	0.2%	0.8%	1.9%	3.6%	6.0%	9.1%
LPG	3.5%	4.1%	4.2%	3.7%	2.8%	1.9%	1.1%	0.6%	0.3%
CNG	0.5%	0.5%	0.6%	0.7%	1.1%	1.6%	2.1%	2.6%	3.2%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Vans

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	28.7%	32.0%	34.7%	33.8%	28.4%	22.1%	16.9%	12.6%	9.0%
Diesel	71.2%	67.5%	63.6%	59.0%	53.4%	46.5%	38.1%	29.6%	22.1%
HEV gasoline	0.1%	0.2%	0.7%	1.9%	3.9%	5.5%	6.6%	6.8%	6.4%
HEV diesel	0.1%	0.3%	1.0%	3.0%	6.8%	10.6%	13.9%	15.8%	16.0%
PHEV gasoline	0.0%	0.0%	0.0%	0.6%	1.9%	3.7%	5.7%	7.4%	8.4%
PHEV diesel	0.0%	0.0%	0.0%	0.9%	3.0%	6.3%	10.6%	15.3%	20.1%
EV	0.0%	0.0%	0.0%	0.5%	1.9%	3.7%	5.7%	8.4%	12.0%
FCEV	0.0%	0.0%	0.0%	0.2%	0.7%	1.6%	2.6%	4.1%	5.9%
LPG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Medium trucks

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	99.9%	99.6%	98.1%	91.3%	78.1%	63.7%	49.8%	36.6%	23.9%
HEV diesel	0.1%	0.4%	1.5%	5.1%	11.5%	17.1%	20.5%	23.0%	25.5%
PHEV diesel	0.0%	0.0%	0.2%	1.7%	5.0%	9.3%	14.5%	18.8%	21.5%
EV	0.0%	0.0%	0.0%	0.9%	3.1%	5.9%	8.9%	12.5%	16.7%
FCEV	0.0%	0.0%	0.0%	0.3%	1.2%	2.4%	4.2%	6.5%	9.3%
CNG	0.0%	0.0%	0.2%	0.6%	1.1%	1.6%	2.1%	2.6%	3.1%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Heavy trucks

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	100.0%	100.0%	98.8%	94.3%	86.4%	75.4%	61.3%	45.9%	30.3%
HEV diesel	0.0%	0.0%	1.2%	4.7%	10.3%	17.8%	27.5%	37.4%	46.3%
FCEV	0.0%	0.0%	0.0%	0.6%	2.1%	4.6%	8.3%	13.2%	19.2%
CNG	0.0%	0.0%	0.0%	0.4%	1.3%	2.2%	2.9%	3.6%	4.1%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Buses

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	98.1%	97.0%	85.3%	65.3%	44.6%	27.9%	16.4%	8.8%	4.1%
HEV diesel	0.1%	1.4%	12.0%	27.3%	39.4%	45.7%	46.9%	45.0%	41.5%
EV	0.0%	0.0%	1.3%	4.3%	8.7%	13.6%	18.5%	23.1%	27.2%
FCEV	0.0%	0.0%	0.3%	2.3%	7.0%	12.7%	18.2%	23.1%	27.2%
CNG	1.8%	1.6%	1.2%	0.7%	0.4%	0.2%	0.0%	0.0%	0.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Inland Shipping

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	100.0%	100.0%	99.7%	99.2%	98.6%	97.7%	96.5%	95.1%	93.7%
LNG	0.0%	0.0%	0.3%	0.8%	1.4%	2.3%	3.5%	4.9%	6.3%

Maritime Shipping

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional	100.0%	100.0%	99.4%	98.4%	97.0%	95.1%	91.9%	87.3%	82.6%
LNG	0.0%	0.0%	0.3%	0.8%	1.4%	2.2%	3.3%	4.9%	6.4%
Conv. + Wind	0.0%	0.0%	0.3%	0.8%	1.6%	2.7%	4.7%	7.8%	11.0%
LNG + Wind	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Appendix 5: Alternative scenario – Powertrain mix

Split of new vehicle sales by powertrain – Alternative scenario

Passenger car

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	50.2%	54.3%	55.2%	39.8%	24.5%	13.5%	2.5%	1.5%	0.5%
Diesel	42.8%	39.4%	36.3%	29.7%	23.0%	14.5%	6.0%	3.0%	0.0%
HEV gasoline	0.2%	0.8%	2.6%	8.5%	14.5%	17.3%	20.0%	16.8%	13.5%
HEV diesel	0.2%	0.5%	1.7%	7.8%	14.0%	16.5%	19.0%	16.5%	14.0%
PHEV gasoline	0.0%	0.0%	0.0%	2.5%	5.0%	10.0%	15.0%	15.5%	16.0%
PHEV diesel	0.0%	0.0%	0.0%	2.5%	5.0%	10.0%	15.0%	15.0%	15.0%
EV	0.0%	0.0%	0.0%	3.0%	6.0%	8.0%	10.0%	13.5%	17.0%
FCEV	0.0%	0.0%	0.0%	1.5%	3.0%	4.5%	6.0%	10.5%	15.0%
LPG	5.9%	4.4%	3.7%	2.3%	1.0%	0.5%	0.0%	0.0%	0.0%
CNG	0.7%	0.6%	0.6%	1.3%	2.0%	2.5%	3.0%	3.5%	4.0%
HEV CNG	0.0%	0.0%	0.0%	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%
PHEV CNG	0.0%	0.0%	0.0%	0.5%	1.0%	1.3%	1.5%	1.8%	2.0%

Vans

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	36.3%	38.0%	38.4%	26.7%	15.0%	11.0%	7.0%	4.5%	2.0%
Diesel	63.4%	60.2%	56.3%	49.1%	42.0%	31.0%	20.0%	14.0%	8.0%
HEV gasoline	0.2%	0.8%	2.2%	5.1%	8.0%	8.0%	8.0%	6.5%	5.0%
HEV diesel	0.2%	1.0%	3.0%	9.0%	15.0%	17.5%	20.0%	17.5%	15.0%
PHEV gasoline	0.0%	0.0%	0.1%	2.5%	5.0%	7.5%	10.0%	10.0%	10.0%
PHEV diesel	0.0%	0.0%	0.1%	4.1%	8.0%	14.0%	20.0%	25.0%	30.0%
EV	0.0%	0.0%	0.0%	2.5%	5.0%	7.5%	10.0%	15.0%	20.0%
FCEV	0.0%	0.0%	0.0%	1.0%	2.0%	3.5%	5.0%	7.5%	10.0%
LPG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Medium trucks

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	99.7%	99.1%	93.0%	71.5%	50.0%	37.0%	24.0%	12.5%	1.0%
HEV diesel	0.3%	0.9%	5.0%	15.0%	25.0%	25.0%	25.0%	27.5%	30.0%
PHEV diesel	0.0%	0.0%	1.0%	6.5%	12.0%	18.5%	25.0%	25.0%	25.0%
EV	0.0%	0.0%	0.0%	4.0%	8.0%	11.5%	15.0%	20.0%	25.0%
FCEV	0.0%	0.0%	0.0%	1.5%	3.0%	5.5%	8.0%	11.5%	15.0%
CNG	0.0%	0.0%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Heavy trucks

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	100.0%	99.6%	94.7%	80.4%	66.0%	48.5%	31.0%	15.5%	0.0%
HEV diesel	0.0%	0.1%	2.0%	8.5%	15.0%	22.5%	30.0%	30.0%	30.0%
FCEV	0.0%	0.0%	0.1%	0.6%	1.0%	5.0%	9.0%	15.5%	22.0%
CNG	0.0%	0.1%	2.0%	3.5%	5.0%	6.0%	7.0%	6.5%	6.0%
HEV CNG	0.0%	0.1%	0.1%	2.1%	4.0%	6.0%	8.0%	13.0%	18.0%
LNG	0.0%	0.1%	1.0%	3.0%	5.0%	6.0%	7.0%	6.5%	6.0%
HEV LNG	0.0%	0.0%	0.1%	2.1%	4.0%	6.0%	8.0%	13.0%	18.0%

Buses

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	98.1%	93.4%	52.5%	34.8%	17.0%	8.5%	0.0%	0.0%	0.0%
HEV diesel	0.2%	2.0%	21.5%	22.8%	24.0%	19.5%	15.0%	7.5%	0.0%
EV	0.0%	0.1%	5.0%	8.5%	12.0%	16.0%	20.0%	25.0%	30.0%
FCEV	0.0%	0.0%	1.0%	6.5%	12.0%	16.0%	20.0%	25.0%	30.0%
CNG	1.7%	4.0%	15.0%	20.0%	25.0%	27.5%	30.0%	27.5%	25.0%
HEV CNG	0.0%	0.5%	5.0%	7.5%	10.0%	12.5%	15.0%	15.0%	15.0%

Inland Shipping

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	100.0%	99.9%	97.0%	94.5%	92.0%	88.5%	85.0%	80.0%	75.0%
LNG	0.0%	0.1%	3.0%	5.5%	8.0%	11.5%	15.0%	20.0%	25.0%

Maritime Shipping

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional	100.0%	100.0%	95.0%	78.5%	62.0%	56.0%	50.0%	42.5%	35.0%
LNG	0.0%	0.0%	5.0%	19.5%	34.0%	37.0%	40.0%	42.5%	45.0%
Conv. + Wind	0.0%	0.0%	0.0%	1.0%	2.0%	3.5%	5.0%	7.5%	10.0%
LNG + Wind	0.0%	0.0%	0.0%	1.0%	2.0%	3.5%	5.0%	7.5%	10.0%

Split of total vehicle stock by powertrain – Alternative scenario

Passenger car

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	60.2%	57.1%	55.8%	51.9%	43.4%	32.6%	21.4%	12.3%	6.6%
Diesel	35.7%	37.8%	38.0%	36.0%	31.8%	26.0%	18.9%	12.4%	7.2%
HEV gasoline	0.1%	0.3%	0.9%	2.9%	6.7%	10.8%	14.5%	16.4%	16.2%
HEV diesel	0.1%	0.2%	0.6%	2.4%	6.1%	10.2%	13.7%	15.7%	15.8%
PHEV gasoline	0.0%	0.0%	0.0%	0.6%	1.9%	4.4%	7.9%	11.2%	13.5%
PHEV diesel	0.0%	0.0%	0.0%	0.6%	1.9%	4.4%	7.9%	11.1%	13.1%
EV	0.0%	0.0%	0.0%	0.7%	2.3%	4.4%	6.5%	8.9%	11.7%
FCEV	0.0%	0.0%	0.0%	0.3%	1.2%	2.3%	3.6%	5.7%	8.8%
LPG	3.5%	4.1%	4.2%	3.7%	2.8%	1.9%	1.1%	0.6%	0.3%
CNG	0.5%	0.5%	0.6%	0.7%	1.1%	1.6%	2.1%	2.6%	3.2%
HEV CNG	0.0%	0.0%	0.0%	0.1%	0.4%	0.8%	1.2%	1.7%	2.2%
PHEV CNG	0.0%	0.0%	0.0%	0.1%	0.4%	0.7%	1.0%	1.3%	1.6%

Vans

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	28.7%	32.0%	34.7%	33.8%	28.4%	22.1%	16.9%	12.6%	9.0%
Diesel	71.2%	67.5%	63.6%	59.0%	53.4%	46.5%	38.1%	29.6%	22.1%
HEV gasoline	0.1%	0.2%	0.7%	1.9%	3.9%	5.5%	6.6%	6.8%	6.4%
HEV diesel	0.1%	0.3%	1.0%	3.0%	6.8%	10.6%	13.9%	15.8%	16.0%
PHEV gasoline	0.0%	0.0%	0.0%	0.6%	1.9%	3.7%	5.7%	7.4%	8.4%
PHEV diesel	0.0%	0.0%	0.0%	0.9%	3.0%	6.3%	10.6%	15.3%	20.1%
EV	0.0%	0.0%	0.0%	0.5%	1.9%	3.7%	5.7%	8.4%	12.0%
FCEV	0.0%	0.0%	0.0%	0.2%	0.7%	1.6%	2.6%	4.1%	5.9%
LPG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Medium trucks

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	99.9%	99.6%	98.1%	91.3%	78.1%	63.7%	49.8%	36.6%	23.9%
HEV diesel	0.1%	0.4%	1.5%	5.1%	11.5%	17.1%	20.5%	23.0%	25.5%
PHEV diesel	0.0%	0.0%	0.2%	1.7%	5.0%	9.3%	14.5%	18.8%	21.5%
EV	0.0%	0.0%	0.0%	0.9%	3.1%	5.9%	8.9%	12.5%	16.7%
FCEV	0.0%	0.0%	0.0%	0.3%	1.2%	2.4%	4.2%	6.5%	9.3%
CNG	0.0%	0.0%	0.2%	0.6%	1.1%	1.6%	2.1%	2.6%	3.1%
HEV CNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HEV LNG	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Heavy trucks

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	100.0%	99.9%	98.6%	93.4%	83.7%	71.3%	56.6%	41.0%	25.4%
HEV diesel	0.0%	0.0%	0.5%	2.8%	7.1%	12.5%	18.9%	24.1%	27.0%
FCEV	0.0%	0.0%	0.0%	0.2%	0.5%	1.6%	4.1%	7.9%	12.9%
CNG	0.0%	0.0%	0.5%	1.6%	2.9%	4.1%	5.2%	6.0%	6.1%
HEV CNG	0.0%	0.0%	0.1%	0.5%	1.7%	3.3%	5.0%	7.6%	11.2%
LNG	0.0%	0.0%	0.3%	1.1%	2.5%	3.9%	5.1%	5.9%	6.1%
HEV LNG	0.0%	0.0%	0.0%	0.5%	1.7%	3.2%	5.0%	7.6%	11.2%

Buses

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	98.1%	96.9%	84.9%	64.3%	42.8%	25.2%	12.7%	5.0%	1.5%
HEV diesel	0.1%	0.6%	6.2%	14.2%	19.9%	21.6%	19.8%	15.4%	9.2%
EV	0.0%	0.0%	1.3%	4.0%	7.4%	11.1%	14.9%	19.1%	23.7%
FCEV	0.0%	0.0%	0.3%	2.0%	5.7%	10.2%	14.6%	19.0%	23.7%
CNG	1.8%	2.4%	5.9%	11.7%	17.8%	22.7%	26.3%	27.9%	27.4%
HEV CNG	0.0%	0.1%	1.4%	3.8%	6.5%	9.2%	11.8%	13.6%	14.6%

Inland Shipping

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel	100.0%	100.0%	99.6%	98.7%	97.4%	95.5%	93.0%	89.7%	86.0%
LNG	0.0%	0.0%	0.4%	1.3%	2.6%	4.5%	7.0%	10.3%	14.0%

Maritime Shipping

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional	100.0%	100.0%	99.3%	96.4%	90.7%	84.2%	75.4%	64.2%	53.8%
LNG	0.0%	0.0%	0.7%	3.4%	8.5%	14.0%	21.2%	29.5%	36.4%
Conv. + Wind	0.0%	0.0%	0.0%	0.1%	0.4%	0.9%	1.7%	3.1%	4.9%
LNG + Wind	0.0%	0.0%	0.0%	0.1%	0.4%	0.9%	1.7%	3.1%	4.9%

Appendix 6: Key scenario input assumptions

Biofuel use - % conventional fuel substituted (total)

		2010	2015	2020	2030	2040	2050
Ethanol	Gasoline	3.0%	6.5%	10.0%	20.0%	35.0%	48.0%
Biodiesel	Diesel	4.4%	7.2%	10.0%	20.0%	35.0%	48.0%
Bio-LPG	LPG	0.0%	2.5%	5.0%	15.0%	25.0%	30.0%
Biogas	CNG	0.0%	5.0%	10.0%	20.0%	35.0%	48.0%
Biogas	LNG	0.0%	5.0%	10.0%	20.0%	35.0%	48.0%
Biocrude/biooil/bio	Ship Fuel	0.0%	0.0%	0.0%	8.0%	25.0%	37.0%
Biokerosene	Kerosene	0.0%	0.0%	5.0%	10.0%	20.0%	40.0%

Percentage average lifecycle GHG reduction over conventional equivalent

		2010	2015	2020	2030	2040	2050
Ethanol	Gasoline	62.7%	55.0%	60.0%	70.0%	80.0%	85.0%
Biodiesel	Diesel	50.8%	55.0%	60.0%	70.0%	80.0%	85.0%
Bio-LPG	LPG	0.0%	55.0%	60.0%	70.0%	80.0%	85.0%
Bio-CNG	CNG	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Biocrude	Ship Fuel	0.0%	55.0%	60.0%	70.0%	80.0%	85.0%
Bio-LNG	LNG	0.0%	55.0%	60.0%	70.0%	80.0%	85.0%
Biokerosene	Kerosene	0.0%	55.0%	60.0%	70.0%	80.0%	85.0%

Annual average distance travelled – Baseline, CPI (km per vehicle)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car	11,646	11,700	11,966	12,025	11,981	11,692	11,411	11,146	10,886
Bus	44,176	43,234	42,283	42,453	41,954	41,603	41,336	41,197	40,844
EUAviation	1,980,493	1,749,838	1,512,690	1,421,891	1,361,763	1,310,968	1,263,914	1,235,174	1,207,696
IntlAviation	2,888,166	2,866,811	2,824,206	2,806,962	2,835,215	2,789,819	2,749,001	2,720,303	2,682,726
PassengerRail	93,928	100,586	109,453	117,220	126,575	133,843	141,598	146,835	151,994
Motorcycle	4,255	4,162	4,099	4,036	3,997	3,961	3,949	3,937	3,934
WalkCycle	519	545	566	612	658	730	804	887	970
Van	11,971	11,678	11,848	12,023	11,974	11,926	11,917	11,871	11,828
MedTruck	29,072	26,790	27,025	27,088	26,697	26,432	26,068	25,729	25,370
HeavyTruck	63,729	57,940	57,770	58,120	57,482	56,682	55,625	54,749	53,790
InlandShipping	30,512	28,980	28,607	28,340	28,382	28,345	28,293	28,043	27,840
MaritimeShipping	97,682	97,409	96,178	95,514	94,691	93,569	92,520	91,935	91,336
FreightRail	67,494	63,742	59,750	62,280	64,029	69,629	75,587	85,784	96,109

Average vehicle lifetime (years)

Car	12
Bus	12
Van	12
MedTruck	11
HeavyTruck	10
InlandShipping	27
MaritimeShipping	27

Average total lifetime km

Mode	2010	2030	2050
Car	139,752	143,777	130,635
Bus	530,106	503,447	490,129
Van	143,651	143,690	141,937
Medium Truck	319,796	293,666	279,074
Heavy Truck	637,287	574,824	537,898
Inland Shipping	823831	799,306	751,692
Maritime Shipping	2,637,417	2,556,657	2,466,067

Appendix 7: Scenario analysis results – supporting data

Consumption of gas (TWh) – Baseline scenario

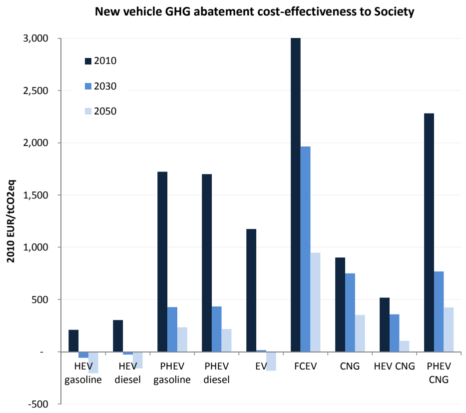
	2010	2015	2020	2025	2030	2035	2040	2045	2050
Baseline CNG	11	13	13	16	26	37	47	56	64
Baseline LNG	0	0	2	6	10	15	23	33	42
Baseline NG total	11	13	15	22	31	52	69	89	106
Baseline - % NG	0.2%	0.3%	0.3%	0.5%	0.8%	1.3%	1.9%	2.6%	3.4%

Consumption of gas (TWh) – Alternative scenario

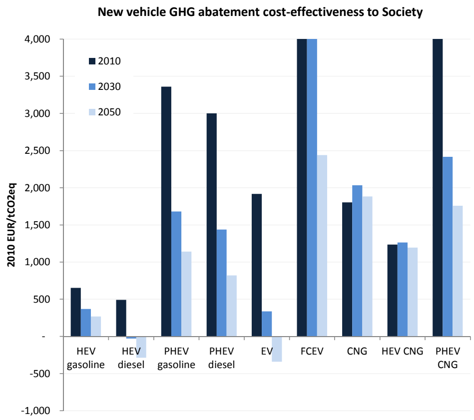
	2010	2015	2020	2025	2030	2035	2040	2045	2050
Alternative scenario - CNG	11	14	21	41	71	103	133	163	189
Alternative scenario - LNG	0	0	6	30	77	126	186	259	323
Alternative scenario NG total	**11**	**14**	**28**	**71**	**148**	**229**	**318**	**421**	**512**
Alternative scenario - % NG	0.2%	0.3%	0.6%	1.5%	3.3%	5.6%	8.6%	12.4%	16.4%

Technology cost-effectiveness to society, Alternative scenario (high fossil fuel price)

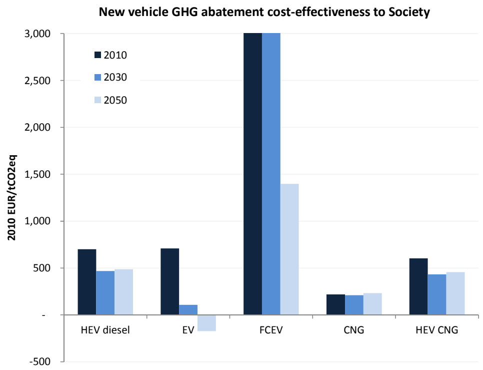
Cars



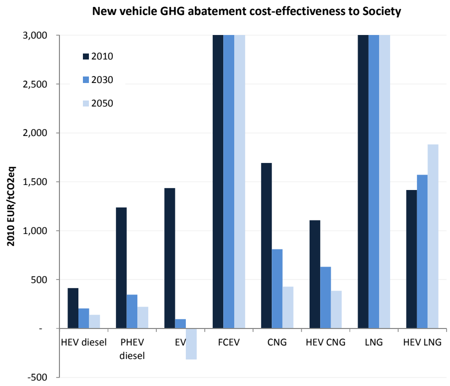
Vans



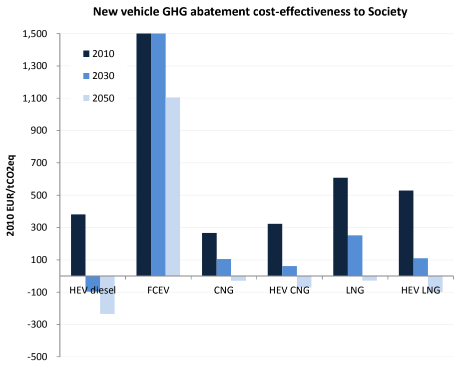
Buses



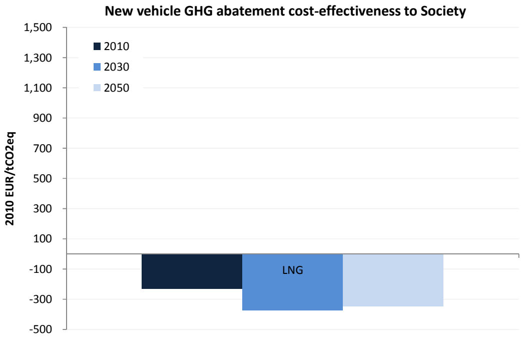
Medium trucks



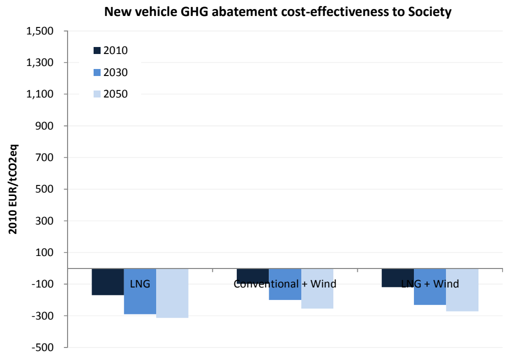
Heavy trucks



Inland shipping



Maritime shipping



Percentage difference emissions of PM in Alternative scenario (compared with Baseline)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.1%	-0.1%	-0.2%
Bus	0.0%	-0.3%	-0.5%	0.2%	4.0%	7.9%	12.8%	17.3%	19.5%
Van	0.0%	0.0%	-0.1%	-0.2%	-0.1%	-0.3%	-1.0%	-2.2%	-3.5%
Medium truck	0.0%	0.0%	0.1%	0.3%	0.9%	1.4%	1.9%	2.3%	2.6%
Heavy truck	0.0%	0.0%	-0.2%	-0.2%	0.3%	0.7%	0.9%	0.9%	0.3%
Total road transport	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.1%**	**0.3%**	**0.3%**	**0.3%**	**0.2%**
Inland shipping	0.0%	0.0%	-0.1%	-0.3%	-0.6%	-1.1%	-1.8%	-2.7%	-4.0%
Maritime shipping	0.0%	0.0%	-0.2%	-1.2%	-3.2%	-5.7%	-9.3%	-14.2%	-18.8%
Total shipping	**0.0%**	**0.0%**	**-0.1%**	**-0.6%**	**-1.7%**	**-3.2%**	**-5.3%**	**-8.4%**	**-11.6%**

Percentage difference emissions of NOx in Alternative scenario (compared with Baseline)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car	0.0%	0.0%	0.0%	-0.1%	-0.4%	-0.7%	-0.8%	-1.2%	-2.2%
Bus	0.0%	0.1%	0.8%	2.6%	6.3%	11.7%	18.3%	24.6%	28.4%
Van	0.0%	0.0%	-0.1%	-0.5%	-1.1%	-2.1%	-3.7%	-5.9%	-8.9%
Medium truck	0.0%	0.0%	0.1%	0.3%	0.8%	1.3%	1.7%	2.0%	2.1%
Heavy truck	0.0%	0.0%	-0.1%	0.1%	0.6%	1.2%	1.7%	2.0%	2.0%
Total road transport	**0.0%**	**0.0%**	**0.0%**	**0.1%**	**0.2%**	**0.4%**	**0.6%**	**0.6%**	**0.6%**
Inland shipping	0.0%	0.0%	0.0%	-0.1%	-0.2%	-0.3%	-0.5%	-0.7%	-1.0%
Maritime shipping	0.0%	0.0%	0.0%	-0.2%	-0.8%	-1.4%	-2.3%	-3.5%	-4.7%
Total shipping	**0.0%**	**0.0%**	**0.0%**	**-0.1%**	**-0.4%**	**-0.7%**	**-1.2%**	**-1.8%**	**-2.5%**