Reducing CO$_2$ emissions in the EU Transportation Sector to 2050

An alternative pathway to reach 2050 abatement targets with lower costs
This document reports the findings of research undertaken by the European Gas Forum, an industry group including Centrica, Eni, E.ON Ruhrgas, Gazprom Export, GDF SUEZ, Qatar Petroleum, Shell and Statoil.

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Preface

Previous reports suggest that achieving Europe’s 2050 emission reduction targets will be neither easy nor cheap and that there may be significant barriers to implementing the changes that will be necessary.

The European Gas Forum (EGaF) was formed to contribute new insights to this critical issue. It produced a study, ‘Making the Green Journey Work’ which examined cost-effective ways to meet an 80% CO₂ abatement target by 2050. The study provided descriptions of three ‘Optimised’ pathways for delivering this emissions reduction target, modelling the power sector in detail, but also considering the industry, buildings and transport sectors. The study took into account several constraints that place upper and lower limits on the pace of implementation and on the mixes of conventional and new technologies to power generation in Europe.

This new study looks at the transportation sector in more detail, exploring alternative pathways to delivering CO₂ abatement in this sector cost-effectively. As before, this study takes into account constraints on the pace of implementation and penetration of technologies in this sector. A complementary study has looked at the residential sector in more detail.

This report is intended to facilitate a transparent debate about how best to achieve emissions reduction targets in the transport sector. It provides policy makers and industry players with descriptions of alternative decarbonisation pathways for the transport sector in order to meet abatement targets in 2050 and compares the potential cost requirements of each.
Executive Summary

The transportation sector has been set a target of reducing GHG emission by 60% by 2050 relative to 1990 levels (based on the European Commission’s 2011 Transport White Paper targets). In this context, this study set out to explore alternative and cost saving pathways to meeting this GHG abatement target in the transport sector.

Research Methodology

An alternative cost saving pathway was developed and assessed against a Baseline pathway scenario, both of which meet the same 2050 GHG emission reduction target. The Baseline scenario is broadly consistent with current Commission views, particularly in relation to potential policies and measures, and is largely based on technological solutions (i.e. more efficient vehicles, or vehicles running on low carbon fuels).

Each scenario was assessed under both a Current Policy Initiatives (CPI) fossil fuel price and a Low fossil fuel price scenario. These price scenarios reflect price assumptions as per the European Commission’s Energy Roadmap 2050. Scenarios were compared using SULTAN, an illustrative scenarios tool, which was recently developed as part of an on-going study for the European Commission. SULTAN is a high-level calculator that can be used to provide indicative estimates of the impacts of EU-level transport policy options, by comparing the outcomes of different scenarios for the evolution of the transport sector from the present day to 2050.

Findings have been presented in two time periods: from present-day to 2030 and beyond to 2050. As with any long-range analysis, uncertainties in future technological and price developments increase in the later time period. In particular, beyond 2030 it is more difficult to predict the cost and performance of as yet unproven technologies, and the future evolution of energy markets in the context of significant global change. Our analysis and assumptions reflect the latest understanding of likely future developments and, where available, are consistent with European Commission assumptions.

Economic Implications of Alternative Scenario

The Alternative scenario is anticipated to deliver cost savings of €68 to €77 billion compared to the Baseline (dependent on gas price scenario used, see Figure E1). Cost savings can largely be attributed to the heavy truck and maritime shipping sectors. Heavy trucks are anticipated to achieve cost savings of €35 to €39 billion by 2050, whereas maritime shipping is anticipated to achieve a cost saving of €25 billion.

Figure E1: Cost savings associated with the Alternative scenario compared with the Baseline scenario by 2050 (€billion, present value in 2010)

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1 Price scenario broadly equivalent to the High Gas Price scenario of the EGaF study “Making the Green Journey Work” (EGaF, 2011).
2 Price scenario broadly equivalent to the Low Gas Price scenario of the EGaF study “Making the Green Journey Work” (EGaF, 2011).
The largest cost savings are anticipated in the next 20 years, up to 2030 (see Figure E2). As natural gas technologies become more established they will become more cost competitive in the later years, leading to reduced savings in the period 2030 to 2050. Cost savings in the period 2010 to 2030 are likely to be in the region of €58 to €67 billion. Cost savings between 2030 and 2050 are estimated to be €10 billion.

**Figure E2: Cost savings associated with the Alternative scenario compared with the Baseline scenario to 2030 and to 2050 (€ billion, present value in 2010)**

![Cost savings comparison chart](image)

**The Key Role of Gas**

Natural gas plays a more significant role in the Alternative scenario compared with the Baseline (512TWh and 106TWh respectively in 2050), contributing to the cost savings achieved, particularly for the heavy truck and maritime shipping segments. Natural gas (CNG and LNG) accounts for 3.4% of final energy consumption in the Baseline scenario in 2050, compared with 16.3% for the Alternative scenario. LNG accounts for the majority of the increase in gas consumption in the Alternative scenario. Together with CNG, the additional natural gas in the Alternative scenario primarily replaces marine fuel (shipping sector) and diesel (HDV sector). The consumption of natural gas by transport mode in 2030 and 2050 is shown in Figure E3 below. Whilst increases in natural gas consumption are evident between the Baseline and the Alternative scenarios across most modes, the most significant increases are associated with heavy trucks and maritime shipping.
Policy Implications

In order to achieve cost benefits and meet CO₂ emission reductions, recognition should be given to the important role that natural gas can play in the transition to a low carbon economy. Natural gas (i.e. CNG and LNG) also has an on-going role in a long term European low carbon transport system, as demonstrated through the Alternative scenario (outlined above). The results shown in the Alternative scenario reinforce those of the Forum’s previous studies – “Making the Green Journey Work” and “Reducing CO₂ emissions in the EU Residential Sector to 2050: An optimised pathway to reach 2050 abatement targets with lower costs” – in that continuing the use of gas is consistent with long term decarbonisation goals and provides economic benefits.

This study also identified a number of potential barriers to successful uptake of the Alternative scenario. These include:

- Widespread availability/provision of refuelling infrastructure for natural gas vehicles;
- Natural gas vehicle purchase prices;
- Overall lifecycle economics of owning a gas-fuelled vehicle; and
- Current consumer and business attitudes towards the purchase and use of natural gas vehicles.

Market barriers also exist, particularly in the segments that have been identified as being key to delivering the main benefits of the Alternative scenario. In the maritime shipping segment, there is the issue of split incentives, whereby the ship operator is often not the same entity as the ship owner, and therefore the party that has to make the investment (in more expensive LNG technology) is not the same party that benefits from the reduced fuel bill. In the heavy trucks segment, the lack of consumer confidence into the benefits that natural gas use could bring is a barrier, together with consumer concerns about availability of refuelling infrastructure.

Therefore, in order to achieve the potentially considerable cost savings in Europe as outlined in the Alternative scenario, such potential barriers and challenges need to be overcome. This could be achieved through implementing a range of policy measures, which are either aimed at stimulating natural gas in the transportation sector (but are currently implemented in few Member States), or that currently exist for alternative technologies but could be adapted towards natural gas. Such options include technology-

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3 Barriers would also need to be overcome in order to achieve the Baseline scenario. For example, provision of battery recharging infrastructure for electric vehicles.
support measures; measures aimed at stimulating the use of alternative fuels more widely; the provision of appropriate gas-based infrastructure; the introduction of vehicle-specific performance targets or standards; fiscal measures; and measures aimed at improving air quality.

It is recommended that further research is undertaken into potential policy measures and how they should be implemented in the EU to achieve the desired results. Measures to be considered with the greatest potential are outlined below:

- In order to promote the use of natural gas ships, the most successful policy measures are likely to include those aimed at **increasing the number and emission limits of Emission Control Areas (ECAs)**.

- Measures aimed at **incentivising the provision of natural gas refuelling infrastructure** should be considered (equivalent measures for other low carbon transport technologies include, for example, the UK’s ‘Plugged-in Places Programme’, which supports the introduction of recharging infrastructure for electric vehicles). This could include allocating specific funding and subsidies loans/grants for the development of public and private natural gas refuelling infrastructure. Recent support for European LNG ‘blue corridor’ projects are a welcome move in this direction.

- Through the introduction of **vehicle purchase/substitution subsidies**, and **subsidised loans for the purchase of natural gas trucks and ships (or their conversion)**, economic barriers to the purchase of natural gas vehicles could be removed.

- The introduction of **technology-support measures** (incentives directed towards specific vehicle technologies, including natural gas vehicle technology) would help to reduce barriers related to natural gas vehicle availability.

- **Taxation-based measures**, such as reduced taxation schemes for natural gas fuels, tax benefit schemes for vehicles and company car reduced income tax schemes could contribute to ensuring running costs associated with natural gas vehicles remain attractive.
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1. **Introduction**

The transport sector is currently responsible for around one quarter of the EU’s Greenhouse (GHG) emissions, and is the second biggest emitter behind the energy sector. 17.2% of the EU’s GHG emissions can be attributed to road transport, 3.3% to maritime and 2.6% to aviation, of which maritime and aviation are experiencing the fastest emissions growth. Despite downward trends in GHG emissions in other sectors, the transport sector continues to see an upward trend, having increased its emissions by 36% between 1990 and 2007.

In 2010, the European Commission introduced the ‘Europe 2020’ strategy which announced plans to decarbonise transport in Europe. This was soon followed in 2011 by the Commission’s 2050 Roadmap and Transport White Paper. The 2050 Roadmap defined 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%. Targets have been set for each of the sectors, and transport sector targets for 2050 are a reduction of 54% to 67% against 1990 emissions levels. The Transport White Paper outlines 40 initiatives aimed at transport over the next decade, and sets a target for a 60% reduction in GHG emissions from transport by 2050 (from 1990 levels).

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**Box 1: Current and future European transport legislation and policy**

**EU Transport White Paper (2011)** presents the EC’s vision for the future of the EU transport system and defines the policy agenda for the next decade. The main target is to achieve a 60% reduction in CO₂ emissions and comparable reduction in oil dependency. These are underpinned by 40 concrete initiatives which are to be developed this decade. There are ten major targets; these include 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.

**Passenger Car CO₂ Regulation** (443/2009/EC) sets a binding limit for new cars of 120g CO₂/km, which is phased in over the period 2012 - 2015. This defines an integrated approach focusing on mandatory reductions to reach an objective of 130g CO₂/km on average for the new fleet through improvements in vehicle motor technology, and further reduction of 10g CO₂/km or equivalent, by other complementary measures. The Regulation indicates that a target of 95g CO₂/km will be specified for the year 2020.

**Van CO₂ Regulations** (510/2011/EC) aims to cut emissions from vans to an average of 175g CO₂/km by 2017 and to 147g CO₂/km by 2020. These cuts represent reductions of 14% and 28% respectively compared with the 2007 average of 203g CO₂/km. As is also the case for passenger cars, penalties would be applied to manufacturers for failure to meet the targets.

**The Directive on the promotion of clean and energy efficient road transport vehicles** (2009/33/EC) requires that lifetime energy and environmental impacts are taken into account when publicly procuring road transport vehicles. It is likely that natural gas vehicles will be among those classed as ‘clean and energy efficient’, therefore encouraging their uptake.

**The Fuel Quality Directive** (FQD) (2009/30/EC) sets a ‘Low Carbon Fuel Standard’, which is a reduction of the lifecycle GHG intensity of liquid fuels by up to 10% by 2020. The legislation applies to all petrol and diesel used in road transport and gas oil used in non-road-mobile machinery. From January 2011, fuel suppliers were required to report annually on GHG intensity of the energy supplied within each European member state.

**The Renewable Energy Directive (RED)** (2009/28/EC) ensures 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, transport, and heating and cooling. Member states retain the discretion as to the mix of these sectors in reaching their national target. A transport specific target has been set of 10% (energy content) deployment of renewable energy by 2020.

**The International Maritime Organization (IMO) Energy Efficiency Design Index (EEDI)** for new ships (MEPC.1/Circ.681) has been developed to create stronger incentives for further improvements in ships’ fuel efficiency. In the first phase (2015-2019) the EEDI will require an efficiency improvement of 10%, and this will be tightened every five years to keep pace with technological developments in emissions reduction measures. The IMO has set reduction rates until the period 2025-2030 where a 30% reduction...
in energy consumption is mandated for most ship types, as calculated from a baseline representing the average efficiency for ships built between 1999 and 2009. The EEDI will be applied to the largest segments of the world merchant fleet, covering as much as 70% of emissions from new ships.

The **EU Emissions Trading Scheme (ETS)** was launched in 2005 and is the first and largest international scheme for trading greenhouse gas emission allowances, aiming to combat climate change through reducing industrial GHG emissions cost-effectively. As of 2012, emissions from all domestic and international flights that arrive or depart from an EU airport will be covered by the EU ETS.

The **EU Effort Sharing Decision** establishes annual binding GHG emission targets for Member States for the period 2013 to 2012, and includes sectors not covered in the EU ETS, including transport, buildings, agriculture and waste. It aims to transform Europe into a low-carbon economy and increase energy security as part of a package of policies and measures on climate change and energy.

(See Appendix 1 for further details of key transport policy and legislation).

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**Box 2: Possible future changes to EU transport legislation**

Both the **passenger car and van CO₂ emission regulations** set short and medium term targets up to 2020, but post-2020 targets are being considered along with changes to the CO₂ test cycle and the inclusion of other GHGs.

The EU is likely to create a strategy for **heavy goods vehicles**, as there is currently no EU legislation aimed at GHG emissions from these vehicles. The EC commissioned a study in 2011 to consider a range of policy instruments for tackling GHG emissions that could be implemented in this sector at the European level. Further work is currently on-going in the form of a strategic review of options to regulate CO₂ emissions and the practicalities of developing a CO₂ test cycle.

The EU is currently involved in pursuing international agreement on global measures to reduce GHG emissions from **international maritime transport**. The International Maritime Organisation (IMO) and the United Nations Framework Convention on Climate Change (UNFCCC) are taking steps to achieve this global agreement. However if this fails, the EC will take action in 2012 due to a commitment to include maritime emissions into the existing EU reduction commitment (Directive 2009/29/EC and Decision 406/2009/EC).

There will be an extension of the designated maritime **Environmental Control Areas (ECAs)**, which requires stringent control of SO\(_X\), NO\(_X\) and PM emissions from shipping, and a progressive reduction in the emission of these pollutants under revised MARPOL Annex VI and NO\(_X\) Technical Code 2008. This will see a reduction in sulphur levels in ship fuel oil from 4.5% to 0.5% by 2020 (subject to a review in 2018). Progressive reductions in NO\(_X\) emissions are included, with more stringent controls being ‘Tier II’ emission limits for diesel engines installed after 2011, and ‘Tier III’ emission limits for marine diesel engines installed after January 2016.

The challenges of reducing GHG emissions from the transport sector are well documented. If existing trends in transport emissions were to continue ‘in a business as usual’ manner, they would undermine the ability of the EU to achieve its long term economy-wide GHG emission reduction targets. It has been estimated that without any policy intervention, transport GHG emissions could be 17% higher in 2050 than in 1990.

In terms of policy intervention, currently there is a common view that decarbonisation of the transport sector could be achieved through large-scale electrification of road and rail. However, in order to deliver the required CO\(_2\) reductions it is imperative that all potential decarbonisation pathways are explored to ensure that this is achieved at minimal cost while still achieving the 60% GHG emissions reduction.

This report presents a Baseline and an alternative transport pathway from 2010 to 2050 for the EU27 region. It focuses on CO\(_2\) released from cars, vans, buses, medium and heavy trucks, and shipping (inland and maritime). These pathways present options to meet the EC 2050 GHG reduction targets in the transport sector in a cost effective manner.
The analysis undertaken in this study complements previous work published by the European Gas Forum (EGaF) which compared a range of scenarios for achieving 80% GHG emissions reduction by 2050, with a particular focus on the power sector. The primary finding was that 2050 carbon reduction targets could be met more cost-effectively by use of pathways with a balanced mix of technologies, among which natural gas plays a significant part in the power generation sector. This study identifies potential cost reductions which could be made in the transport sector. The alternative scenario presented in this study is also based on the ethos of the EC Transport White Paper and previous work undertaken for the Commission.

Whilst it is acknowledged that it would have been beneficial to undertake a cost-optimised approach to exploring alternative pathways, fewer cost-optimisation models currently exist or are accessible for the transport sector. The transport sector is considerably more diverse and complex than other sectors, making cost optimisation modelling extremely difficult to achieve for the whole of the European transport system. Cost-optimisation is commonly used to investigate future options in sectors where the end service provided is highly standardised (for example, electricity generation or residential heat and power). For transport, where different modes offer a different service in terms of speed, accessibility, range and price, it is not straightforward to model the decisions and behaviour of users dynamically in order to endogenously model the take-up of different options. Therefore this approach was not taken. Instead the SULTAN tool, an illustrative scenario modelling tool developed for the Commission, was used to undertake the analysis (see Section 2.4).

4 Making the Green Journey Work, EGaF, 2011
2. Methodology

2.1. Overview

An alternative yet cost effective scenario for the transport sector (hereafter referred to as “Alternative scenario”) was developed and compared with two ‘reference’ scenarios: a Business as Usual (BAU) scenario and a Baseline scenario. The BAU scenario developed assumes that current and proposed policy measures go ahead, but no further policy action is taken. The BAU scenario is consistent with work currently being undertaken for the Commission. The Baseline scenario has been developed to meet the 2011 EC Transport White Paper GHG emission reduction targets, and is achieved through an illustrative suite of policies that have previously been agreed with the Commission and fitting the ethos and priorities of recent Commission policy position papers on transport. It is focussed on technological solutions. These are described in more detail in subsequent sections of this report. Therefore the Alternative scenario utilises alternative technological and fuel solutions, in a cost-optimised manner where possible, whilst achieving the same 2050 GHG reduction targets for the transportation sector as the Baseline scenario.

Whilst this study has similar aims to a recent EGaF study focussed on the residential sector, i.e. identifying alternative pathways to achieving desired GHG reductions by 2050 including cost savings, key differences in the methodologies used should be highlighted. The residential study uses a formal energy system optimisation model, enabling analysis of the key technology and infrastructure trade-offs, and reflects as realistically as possible the cost of adoption of end-user technologies. In contrast, this study for the transport sector uses an illustrative scenarios tool (see Section 2.4 for further details), which acts as a high-level calculator that can be used to provide indicative estimates of the impacts of policy options through comparing the outcomes of different scenarios for the evolution of the transport sector from the present day to 2050 (rather than an optimisation model). As previously outlined, it is very difficult to model the transport sector accurately using a cost-optimisation approach, and very few examples exist in the literature.

2.2. GHG CO₂ targets for the transportation sector

As highlighted earlier, the EC’s 2050 Roadmap explored 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%, with the transport sector’s targets being a reduction of between 54% and 67% in emissions against 1990 levels. The EC’s Transport White Paper also set targets for GHG reduction for the transport sector. Specifically, these are:

1. In 2030, all modes (excluding maritime) are assumed to achieve a 20% reduction in emissions compared to 2008 levels (roughly an 8% increase in 1990 GHG emissions levels); and
2. In 2050, all modes (excluding maritime) are assumed to achieve a 60% reduction in emissions on 1990 levels. The maritime sector is assumed to achieve a 40% reduction in emissions compared to 2005 levels.

This study compares the baseline scenario with an alternative scenario with increased use of natural gas, both of which meet the EC’s Transport White Paper GHG reduction targets for 2030 and 2050.

2.3. Energy price scenarios

Two sets of fossil fuel price projections have been adopted in order to provide a sensitivity analysis to this key metric.

The first set of prices is from the “Current Policy Initiatives” (CPI) scenario in the European Commission’s Energy Roadmap 2050. This reflects the latest policies adopted in Europe and recent trends in fossil fuel prices, and is broadly comparable with the High Gas Price Scenario used in previous EGaF studies.
The second set of prices presents an alternative view, with low fossil fuel prices driven by more subdued economic growth and favourable fossil fuel reserves, and is from the Low Fossil Fuel Price scenario in the Energy Roadmap 2050\(^5\). It is broadly comparable with the Low Gas Price Scenario used in previous EGaF studies.

Fossil fuel prices, along with derived electricity prices are presented in Figure 1. The levelised electricity wholesale cost shown in Figure 1 includes only the fixed and variable costs (including fuel costs) of electricity production; it does not include any taxes on fuels and electricity, ETS auction payments or grid and sales costs, and should therefore not be taken as the wholesale price of electricity.

**Figure 1: Fossil Fuel Price Assumptions (Source: EC Energy Roadmap Scenarios)**

These fuel price projections were used as a basis to project known transport fuel retail prices (in 2010) throughout the time series for fuels including liquid fossil fuels, natural gas, electricity and hydrogen. These price estimates include the margin required to cover the cost of refuelling infrastructure in each case. For electricity, the price estimates used are consistent with those used in the EU Energy Roadmap 2050 and EU Transport White Paper. Full details of the fuel price assumptions used in this study can be found in Appendix 2.

### 2.4. SULTAN – Illustrative Scenarios Tool

Scenarios were explored using SULTAN, a transport sector illustrative scenarios tool that has been developed as part of the EC’s on-going ‘EU Transport GHG: Routes to 2050’ study. SULTAN is a high-level calculator that can be used to provide indicative estimates of the impacts of EU-level transport policy options, by comparing the outcomes of different scenarios for the evolution of the transport sector from the present day to 2050.

There are many possible routes to achieving European long-term targets for GHG emission reductions in the transport sector. A range of different policy options are available to policymakers, each of which would have different impacts on the type of transport that is undertaken, the technologies used to provide transport services and the energy sources used to power them. There is a need to begin considering what might be required in the long term to meet Europe’s ambition of reducing GHG emissions from transport by 60% compared with 1990 levels, and the relative advantages and disadvantages of different pathways. The SULTAN tool has been developed as part of work for the European Commission in order to scope out and compare different routes to meeting 2050 targets.

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The tool covers the EU-27 at an aggregate level and considers all major modes in the European transport system on road, rail, air and water. It includes domestic, intra-European and international transport to/from Europe. Scenarios are created as a series of inputs that define the volume and type of transport, the types of vehicles used, the technologies employed and the energy supplies used to power them, as impacted by different policy measures. The SULTAN tool then calculates the impact of these inputs on total GHG emissions, related impacts such as air quality pollutant emissions and energy security, and high-level costs. In doing so it also provides information on other parameters, including the penetration of different vehicle technologies into the overall fleet (through a simplified vehicle stock model), aggregated consumption from different energy sources and the split of transport demand by different modes. Inputs on the costs of different vehicle technologies and fuels are also used to calculate overall societal costs throughout the time period, so that the total cost to society of each policy scenario can be derived (using appropriate discounting of future years).

As part of the original development of the SULTAN tool, a complete ‘business as usual’ policy scenario was created. This is based on existing European transport modelling work, including the PRIMES/TREMOVE model used by the European Commission for their recent Energy Roadmap and Transport White Paper policy documents, and is described in more detail below. The direct and indirect emission factors (including well-to-wheels emission factors) used in SULTAN are therefore consistent with the modelling previously undertaken by the Commission in the preparation of these policy documents. New policy scenarios are created by estimating the impact of additional policies and measures on the business as usual scenario.

A number of policy scenarios, investigating alternative routes to achieving European GHG reduction targets in transport, have already been created using SULTAN. This study adds to this body of work by creating new scenarios that investigate whether there are other, more cost effective pathways for decarbonising the transport sector in Europe.

The SULTAN tool is publicly available from the ‘Routes to 2050’ website, www.eutransportghg2050.eu.

2.5. Business as Usual (BAU) reference scenario

The ‘Business as Usual’ (BAU) scenario was developed in 2011 as part of the European Commission’s work on transport policy. It is largely based on PRIMES (2011) modelling used by the Commission in the 2011 Transport White Paper, and includes the most up to date projections on GDP and transport demand. It also includes existing and recently implemented policies affecting the transport sector, including the 2020 targets on vehicle test cycle emissions for passenger cars and vans, and the IMO’s Energy Efficiency Design Index targets for maritime shipping. The BAU scenario assumes that all existing and currently planned policies are in place, and the associated targets are met. Figure 2 shows the total combined (life cycle) GHG emissions for the BAU scenario out to 2050. The Transport White Paper targets for 2030 and 2050 are indicated on the figure, as is the 1990 GHG emissions level. It is anticipated that the total GHG emissions will decline over the period to 2050. This can largely be attributed to the action taken by vehicle manufacturers to meet the passenger car CO₂ regulations. However, it is anticipated that in a BAU scenario, neither the 2030 nor 2050 White Paper target will be met (study undertaken for the Commission). In fact, total levels of GHG emissions are estimated to be 6% over the 2030 target, and 148% over the 2050 60% reduction target in their respective years.

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6 EU Transport GHG Emissions: Routes to 2050 II - http://www.eutransportghg2050.eu/
2.6. Baseline reference scenario

The second ‘reference’ scenario is referred to as the Baseline. Reductions in order to meet the EC Transport White Paper targets are achieved through an illustrative suite of policies that are consistent with analysis undertaken for the Commission and fitting the ethos and priorities of recent Commission policy position papers in transport. The baseline represents a scenario for achieving White Paper targets that is broadly consistent with Commission views, particularly in relation to potential policies and measures. The focus of the baseline scenario is on technological solutions, i.e. more efficient vehicles or vehicles running on low carbon fuels. Pricing signals (e.g. internalisation of externalities, some tax harmonisation across fuels) are also used.

Figure 3 shows the total combined (life cycle) GHG emissions for the baseline scenario, which meets the 2030 and 2050 White Paper targets. Emissions fall some way beneath the 2030 target – this is due to the need to implement policies earlier in order to meet the 2050 target. Key inputs and assumptions regarding the baseline scenario are discussed in more detail below.
As a result of new vehicle CO\textsubscript{2} and energy efficiency standards, the baseline anticipates that there will be large reductions in vehicle emissions by 2050. This is based on targets for the reduction of direct emissions of approximately 80% for cars, vans and buses, 60% for heavy trucks and 50% for shipping. Reductions are anticipated to be achieved mainly through a shift to lower emission powertrains (e.g. hybrids, electric/hydrogen, natural gas), along with assumptions on efficiency improvements for specific types of powertrains. It is also assumed that year-on-year efficiency improvements in the region of 1.5% for aviation are made (though this is also included in the BAU scenario as an existing target).

The baseline assumes that operational efficiency is greatly increased, responding to a range of policy signals (pricing, regulation, etc.). Operational efficiencies in maritime shipping resulting in 10% energy efficiency improvements by 2050 and a 10% increase in load factor by 2050 (both compared to business as usual) are assumed to occur. The baseline scenario also assumes a 5% increase in load factor against the business as usual scenario by 2050 for road freight.

Biofuels are expected to play a significant role in achieving decarbonisation in some transport modes, and it is assumed that biofuels improve from an average 55% reduction in GHG intensity in 2010 (compared with equivalent fossil fuel) to 85% reduction in 2050. Biofuels replace conventional hydrocarbon fuels in road, rail and inland shipping (40% by 2050), maritime bunker fuel (35% by 2050) and aviation bunker fuel (40% by 2050, a White Paper target). To this end, biofuels are expected to enter circulation as a substitution for gasoline, diesel, natural gas, aviation and marine bunker fuel. This high level of biofuel deployment is broadly consistent in scale with EC assumptions in the 2011 Transport White Paper.

In terms of mode shift, passenger transport is assumed to experience a low-level shift from cars to public transport; up to 15% shift in 2050 for urban traffic, and a 5% shift in 2050 for non-urban and motorway traffic. Freight transport is assumed to see an additional shift from heavy trucks to rail and inland shipping, with up to 20% shift in 2050 for motorway traffic and a 4% shift for non-urban traffic.

Fuel prices are based on Commission’s ‘Current Policy Initiatives’ (CPI) scenario (central) and the ‘low’ price variant from the Energy Roadmap. In terms of fuel taxes, GHG and air quality external costs are internalised by adding them to the energy carrier cost as tax (in addition to existing taxes), phased in gradually from 2020 to 100% internalisation by 2050. Some harmonisation of fuel taxes across all modes (mainly impacting on aviation and maritime shipping by increasing fuel taxes to bring them in line with other modes) has been assumed to take place, starting in 2030 and moving up to 30% tax harmonisation by 2050. Finally, company car tax reform takes place to remove perverse incentives for company car ownership, and to improve the efficiency of these types of vehicles.
3. Fuel and Technology Options

This section provides an overview of the potential fuel and technology options that are available to the transport sector to provide CO₂ abatement. Further information is provided on a range of key gas-based technologies, including current status, transport mode applicability, CO₂ abatement potential, the consideration of co-benefits, challenges and costs. This is followed by an overview of other technologies available to the transport sector.

3.1. Gas-based technologies

Natural gas (NG) is a clean burning fuel that currently has relatively low levels of use in the European transport sector. Natural gas can be carried in vehicles either in a compressed format (CNG) or liquefied format (LNG) in insulated tanks. Natural gas can be used across the range of transport modes, though technology development is more advanced in some modes than others.

Natural Gas engines

There are two types of engine capable of using natural gas: spark ignition engines (often termed bi-fuel vehicles) and compression-ignition dual-fuel engines. An engine designed to run on 100% natural gas requires spark ignition, and is therefore generally used in either dedicated natural gas vehicles or in vehicles that are designed to run on either natural gas or gasoline (bi-fuel vehicles). Bi-fuel vehicles with a CNG and gasoline fuel tank have the advantage of an enhanced driving range, together with flexibility if CNG refuelling infrastructure is not available. Diesel engines tend to be more efficient than gasoline engines, as they utilise a compression-ignition cycle rather than a spark ignition cycle. Dual-fuel natural gas vehicles are able to utilise the more efficient compression-ignition cycle, by using a small amount of diesel as a ‘pilot fuel’ to initiate combustion (using the heat generated by compression), but replacing the rest of the diesel with natural gas. The level of natural gas used in dual-fuel engines varies depending on the engine load. Only a small amount of energy is required when the engine is idling, the majority of which is provided by the diesel pilot fuel. However, as the engine load and energy consumption rises (for example, cruising on a highway), so does the proportion of natural gas in the dual fuel mix. The natural gas used either type of engine can be derived from either fossil gas or biogas (refined into biomethane). One of the main advantages of using biomethane is that the overall GHG emissions are lower on a well-to-wheel basis, particularly if biomethane is produced from waste products. Biomethane has already proven itself as a viable fuel source both financially and also in emissions reduction. It is currently fuelling many buses and refuse trucks around Europe.

Road transport vehicles with natural gas spark-ignition engines have significant CO₂ reduction potential over gasoline engine vehicles: the improvements are comparable to diesel on a well to wheels basis. There is potential to reduce CO₂ emissions by 25% (EPA, 2002). In addition to reductions in CO₂ emissions, the use of natural gas spark-ignition engines has other environmental co-benefits, including the potential for significant air pollutant emission reductions. In light-duty vehicles (LDVs), pollutant emission reductions include 90% reduction in carbon monoxide (CO), 35-60% reduction in oxides of nitrogen (NOₓ), 50-75% reduction in non-methane hydrocarbon emissions, fewer toxic and carcinogenic pollutants, little or no particulate matter (PM); and elimination of evaporate emissions (EPA, 2002).

Heavy Duty Vehicles (HDVs) using natural gas spark-ignition engines are likely to see a 50% reduction in PM compared to diesel vehicles, a significant reduction in CO emissions, at least a 50% reduction in NOₓ and VOCs, and drastically reduced toxic and carcinogenic pollutants. Natural gas-fuelled vehicles are also likely to be quieter, and therefore have positive noise reduction benefits (reduced benefits are likely for dual-fuel vehicles). Hybrid natural gas vehicles are not currently available in Europe, although they may be an option for the future, offering even greater GHG and air pollutant emission reductions.

Compressed Natural Gas (CNG)

CNG is most commonly used in passenger cars, light goods vehicles (LGVs), and heavy duty vehicles (HDVs) with a short to medium driving range (under 400km). A large proportion of the CNG vehicles currently in use are urban fleet vehicles, such as buses, refuse collection trucks, and commercial delivery
vehicles. However, the vast majority (1 million) of CNG vehicles in the EU are passenger cars. A number of manufacturers currently offer CNG vehicles for sale, including major OEMs such as Fiat, Opel, Volkswagen, Citroen, Renault, Volvo and Mercedes-Benz.

The use of CNG in urban fleet vehicles is very attractive, as such vehicles regularly return to their own depots to refuel, meaning that the requirement for widespread infrastructure is reduced. They are particularly attractive where refuelling can take place at a depot near high pressure gas distribution networks (e.g. the edge of a city) to minimise infrastructure costs. Heavy duty fleet vehicles are also typically larger in size, meaning that storage of the fuel (CNG requires roughly five times the storage volume of diesel due to its lower density) is not so much of an issue. However, in recent years developments have been made with regard to CNG storage in vehicles, making this less of a barrier for smaller vehicles such a passenger cars and vans. CNG is not considered suitable for aviation, primarily because its lower energy density means that there is insufficient onboard storage space for an adequate flying range.

### Box 3: CNG applications in Europe

#### Europe - The deployment of CNG vehicles and infrastructure varies greatly over Europe. Countries such as Italy, Ukraine, Russia, Armenia, Germany and Sweden have relatively high uptake, compared to others which have no or very few natural gas vehicles (NGVs). Europe-wide, there are around 1.5 million CNG vehicles. Of these, 1.4 million are light duty passenger cars or light duty commercial vehicles, approximately 46,000 are buses and 51,000 are trucks. There are a total of 4,000 refuelling stations, of which approximately 2,700 are public. There are also 32 LNG or L-CNG stations. (Source: NGVA Europe, 2012)

#### Italy - Italy currently has 54% of Europe's CNG vehicles, with a total of 761,340 vehicles (June 2011). Of these, 757,840 are cars or light-duty commercial vehicles, followed by 2,300 medium/heavy duty buses (used in urban areas), and 1,200 medium/heavy duty trucks (primarily refuse collection vehicles). Vehicles are able to fill up at the 858 refuelling stations across the country. The success of CNG vehicles in Italy is in part due to the availability of small and medium-sized CNG-powered Fiat cars that are available ex-factory with CNG engines. There are also a range of financial incentives that have also contributed to the uptake of CNG vehicles, in addition to reduced running costs compared to equivalent vehicles (the saving in fuel costs per km for a medium-sized car running on natural gas is estimated to be approximately 60% compared to an equivalent petrol car and 33% compared to a diesel car). There are financial incentives for conversion to CNG of between €350 and €650 dependent on which Euro standard the vehicle complies with. Euro 0 to Euro 3 CNG vehicles (new OEM and converted) are not subject to road tax increases that were introduced in 2007 for such vehicles. In some Italian regions there are also incentives for building new CNG refuelling stations, with a maximum of €150k per station/firm. Finally, natural gas has favourable taxation compared with other automotive fuels:

<table>
<thead>
<tr>
<th>Automotive fuel</th>
<th>Fuel tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>€0.0618 / kWh</td>
</tr>
<tr>
<td>Diesel</td>
<td>€0.0422 / kWh</td>
</tr>
<tr>
<td>LPG</td>
<td>€0.0189 / kWh</td>
</tr>
<tr>
<td>CNG</td>
<td>€0.003 kWh</td>
</tr>
</tbody>
</table>

*Source: NGVA Europe, 2011*

*IVECO Stralis CNG refuse truck (l) and Mercedes-Benz Econic CNG truck, Athens (r) Source: NGVA Europe*
Liquefied Natural Gas (LNG)

LNG has a significantly higher energy storage density compared to CNG; 1.8 litres of LNG has the energy equivalent of 1 litre of diesel, or 5 litres of CNG. For this reason, LNG is typically used in long-distance heavy duty vehicles (HDVs), allowing them to maintain an acceptable driving range. There is no difference in the engine technologies for LNG/CNG, only in the fuel supply, distribution and storage (both at point of refuelling and on board the vehicle).

There are a small but growing number of LNG ships currently in operation, and LNG is considered to be a potential future fuel for a wider range of ships. It is anticipated that LNG in shipping (both inland and maritime) will become much more economically attractive. This is principally for ships making regional journeys wholly or partially within Emission Control Areas (ECAs) where LNG is available. ECAs for NOx and SOx are therefore a significant additional incentive for LNG use in the maritime sector, as LNG-fuelled ships will be able to meet the Tier III emission levels and SOX requirements of ECAs without the installation of expensive exhaust gas scrubbers (IMO, 2009). LNG conversion is possible for ships, but LNG is most relevant for new builds due to the substantial modification of engines and allocation of extra storage capacity is required (IMO, 2009).

The use of LNG can have positive benefits in terms of reductions in CO2 emissions; exhaust CO2 emission reductions of 3-9% (compared with diesel engines) have been demonstrated in HDVs, with further improvements possible. There are also air pollutant emission benefits to be achieved through the use of LNG in shipping, including lower emissions of NOx (up to 85-90%), SOx (up to 100%) and PM (up to 50%). LNG also has the benefits of no visible smoke or sludge deposits (therefore extending engine life). However, there will be increased emissions of methane (CH4), reducing net global warming benefit from 25% to about 15% in shipping applications (IMO, 2009). Sulphur is removed from the fuel when liquefied, which makes LNG an excellent substitute fuel for the maritime sector when SOx limits become mandatory. An LNG truck can have a range of up to 1,000km, and produces half the noise of a diesel truck. Compared to trucks with a Euro V diesel engine, a dual fuel LNG truck running on 50% LNG can achieve a 13% reduction in CO2 and a 33% reduction in PM emissions. However, using a high fuel mix of 85% LNG, trucks can achieve a 21% reduction in CO2 and a 56% reduction in PM emissions. Figure 4 and Figure 5 provide some examples of the potential air pollutant emission reductions that could be achieved.

*Figure 4: Emissions reduction potential for different fuel and engine configurations for maritime shipping (Source: Wartsila)*
Box 4: LNG applications in Europe – Maritime sector

It is currently estimated that there are 300 LNG carriers worldwide. A fairly large proportion of these vessels use LNG for propulsion. By means of an example, the British Emerald LNG carrier was built in 2007 - It has a dual-fuel gas-diesel engine and consumes around 50,000 tonnes of fuel annually. However, a similar sized ship that uses steam boilers would use around 64,000 tonnes (approximately 50% boil-off gas and 50% oil). Conventional engines can also be used in LNG carriers, but then an on-board facility for re-liquefaction of boil-off gas is required.

There is currently limited use of LNG in other ship types. However, this fuel type is particularly suitable for short distance shipping due to the volume of fuel carried and need to refuel (maximum of seven days sailing without refuelling). Such vessels would include LNG powered car and passenger ferries. Short sea shipping presents a major opportunity for LNG use in the maritime sector, as short distance sea traffic accounts for approximately one third of global marine transport (Boisen, 2011).

Recently converted LNG ship (dual fuel). Source: NGVA Europe

Box 5: LNG applications in Europe – HDV sector

There are currently a number of LNG terminals already in operation, primarily concentrated along the Southern European coast. LNG is also able to reach/supply any point of Europe due to the well-developed transportation of the fuel by road tankers. However, the number of refuelling stations for LNG in Europe is currently limited, at around 30 in mid-2011. The introduction of L-CNG refuelling stations (liquid to compressed natural gas stations – enabling CNG to be brought to areas where a pipeline does not currently exist) increases the availability of LNG to HDVs. However, more stations are required across Europe in ‘LNG Blue Corridors’ to encourage further uptake of LNG in the long-distance HDV sector. A number of vehicle manufacturers, including IVECO, Daimler, Scania and Volvo currently produce a range of dedicated and/or dual-fuel natural gas HDVs.

Mercedes-Benz Econic dedicated LNG HDV. Source: NGVA Europe

Natural Gas Refuelling Infrastructure
One of the regularly cited barriers to the wider uptake of natural gas in the transport sector is the availability of refuelling infrastructure. A recent report by the Expert Group on Alternative Fuels (2011) considers the infrastructure required for alternative fuels, including natural gas. An extensive natural gas distribution grid (for residential, industrial and power plant applications) currently covers most of Europe. Methane needs to be compressed and dispensed from the current grid for CNG, whereas methane needs to be handled through the supply chain as a cryogenic liquid for LNG, and could be sourced from LNG terminals or produced in liquefaction facilities in other locations. Where areas do not have access to the gas grid, it is possible to supply LNG via trucks to filling stations able to supply both LNG and CNG (L-CNG stations). Some countries currently have a wide and expanding network of CNG related infrastructure, including fuelling stations, gas upgrading plants and gas injection. However, in a large number of other countries, there is a limited public network of filling stations.

There are currently around 3,000 CNG refuelling stations in the EU (including EFTA countries), and approximately 1.5 million CNG vehicles. Italy and Germany both have a developed network of CNG refuelling stations, and subsequently have the highest numbers of CNG vehicles in Europe. In June 2011, Italy had 761,340 CNG vehicles and 858 refuelling stations (of which 811 were public). There were 94,890 vehicles in Germany and 900 refuelling stations (of which 720 were public). Countries such as France and Spain have extremely low numbers of refuelling stations but they rely on urban fleet vehicles (trucks and buses) returning to private depots.

One of the key barriers to widespread CNG use is the high investment costs required in infrastructure. The costs and requirements associated with natural gas infrastructure are discussed in more detail in Box 6.

The use of natural gas will make most sense when the infrastructure can be worked as hard as possible in order to minimise its impacts on costs. Examples of European natural gas infrastructure are shown in Box 7.

**Box 6: Natural gas refuelling infrastructure costs and requirements**

Europe already has an extensive natural gas transmission and distribution infrastructure, developed for residential and industrial consumers. However, there is comparatively little natural gas vehicle refuelling infrastructure. The investment required to establish adequate supporting infrastructure is a barrier to adoption of natural gas vehicles compared to liquid fossil fuel vehicles, which are at an advantage as petrol and diesel refuelling infrastructure is already very well established.

A typical CNG station can cost between €200,000 and €400,000 (depending on the compression capacity of the installation), which is the cost of retrofitting an existing gasoline fuelling station with CNG. However, there may be additional costs, such as those associated with providing a new pipeline if one does not already exist (€300-€600 per metre), and these costs assume that much of the civil engineering infrastructure costs have already been accounted for. Therefore, where new CNG/LNG stations are being constructed (for buses, refuse vehicles or other fleet vehicles, investment costs are likely to be much higher. Such stations can cost €1,000,000 or more, with Madrid’s new CNG bus refuelling infrastructure (capable of refuelling the whole fleet) costing €6,000,000.

L-CNG refuelling stations require that LNG is supplied via heavy duty road tankers. A stationary LNG tank for storage and feeding the installation needs to be installed, as well as a transfer pump to convert LNG into CNG, and the converters. It is estimated that the cost of a L-CNG station for trucks, buses, light commercial vehicles and passenger cars would be in the region of €700,000 (one LNG and two CNG filling pumps).

For private passenger cars and commercial fleets (cars/vans), CNG needs to be available in 10% of urban filling stations and 25% of motorway filling stations – such filling stations should be available at least every 150 km along motorways (or major highways) and local distribution in urban/built up areas. HDV requirements vary quite considerably depending on use. LNG refuelling for goods vehicles needs to be developed in conjunction with major trucking companies and operators. LNG refuelling should be available every 400 km in L-CNG filling stations (enabling both CNG for LDV and LNG for HDVs). For Europe as a whole, the capital investment needed is offset against lower running costs for natural gas vehicles. The challenge lies in financing these investments in order to develop the market.

An infrastructure challenge also exists for other alternative fuel supplies. Whilst an electricity distribution network is well established in Europe, charging connection points are not. On an individual basis, the investment cost for electricity charging stations are considerably lower than natural gas refuelling stations: around €20,000 for a public station and €400 for a basic home charge point. Investment costs strongly depend on the works (e.g. digging) and labour required. However, electric vehicle charging
points are likely to service a significantly lower number of vehicles than a natural gas refuelling station, due to the long charging times. Analysis suggests that the annualised investment cost per vehicle served for a public natural gas station is broadly similar to that of electric vehicle charging infrastructure. For private fleet natural gas refuelling stations, where the infrastructure can be used more intensively than public infrastructure today (which sees low use due to comparatively low number of natural gas vehicles on the road), the economics of infrastructure investment are even more compelling.

Hydrogen refuelling infrastructure is considerably less advanced, because a Europe-wide distribution network does not exist and would need to be established. This would require significant investment. Refuelling stations would also need establishing, and recent estimates for fuelling station investment costs range from €1.6 million to €600,000, depending on size and throughput. Analysis indicates that hydrogen infrastructure would be the most expensive to develop by some margin.

**Box 7: Examples of natural gas infrastructure in Europe**

<table>
<thead>
<tr>
<th>L-CNG station, Fordonsgas</th>
<th>LBM station, Fordonsgas</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNG Dispenser</td>
<td>CNG station, Bohlen Doyen</td>
</tr>
<tr>
<td>CNG Bus Depot, Madrid</td>
<td></td>
</tr>
</tbody>
</table>

*Source: NGVA Europe*

**Hydrogen Fuel Cell Vehicles**

Fuel cells convert the chemical energy of hydrogen into electrical energy that can be used to power vehicles. Because they convert hydrogen to electricity via an electro-chemical rather than combustion process, fuel cells have a higher achievable energy efficiency than internal combustion engines. Hydrogen can be used as a transport fuel in internal combustion engines (ICE) and fuel cell electric vehicles (FCEV),
the latter being more popular option because of their greater efficiency. Fuel cell vehicles have an operational efficiency of over 50%; more than twice that of a typical hydrogen internal combustion engine (IEA, 2010a). However, both types of hydrogen powertrain face barriers from hydrogen storage issues and a lack of refuelling infrastructure. Hydrogen is seen as a clean fuel, as tailpipe emissions are negligible. However, overall lifecycle emissions are significantly affected by both the hydrogen production pathway (although, this can be mitigated by the use of renewable/low carbon production routes) and the vehicle combustion technology. The majority of hydrogen today is produced from fossil fuels – natural gas reformation and coal gasification (IEA, 2010a). Electrolysis of water and gasification of heavy fuel oils are also common. Other processes using renewable energy are being researched. These include:

- Photoelectrolysis, converting sunlight into hydrogen;
- Photobiological processes, which rely on organisms that produce hydrogen as a metabolic waste;
- Thermochemical processes, which decompose water at high temperatures using heat from nuclear or solar energy (EC, 2006).

It is anticipated that in the long-term hydrogen would be produced exclusively from renewable/low carbon sources (primarily from electrolysis of water), so that it can be used as a low-carbon fuel.

The first applications of hydrogen have been in the road transport sector. The Clarity fuel cell car is currently available on a limited basis from Honda, and a number of other car manufacturers, including Toyota, Mercedes-Benz and Hyundai, are planning to have models available for sale by 2015. Hydrogen fuel cell technology has also been demonstrated in city buses. At least one European developer plans to market a fuel cell hybrid 7.5 tonne truck. As production volumes will initially be low, this is likely to be a niche product. Hydrogen could be used as fuel for fuel cells in the shipping sector, although it is unlikely that it would be a viable option, due to the need to reduce costs, and improve durability and power density. Hydrogen could be a viable fuel source for a range of transport modes if it was to achieve a significant reduction in life-cycle GHG emissions, which would require a renewable source of hydrogen (AEA et al, 2009; Eykerman, 2009).

Hydrogen use offers 100% reduction in tailpipe CO2 emissions. However, this does not take into consideration the full Well to Wheels life-cycle CO2 impacts of this fuel, which depends on how the hydrogen was produced. Like CO2 emissions, there are negligible air pollutant exhaust emissions for hydrogen fuel cell vehicles. Even including fuel production processes, significantly lower levels of NOx, SOx and PM emissions can be achieved through using FCEVs compared to petrol internal combustion engine (ICE) vehicles on a Well to Wheels basis.

Hydrogen vehicles will experience greater infrastructure challenges than natural gas vehicles, in that the current almost total lack of availability of hydrogen infrastructure will limit current uses to fleets that regularly return to depots. Unless hydrogen is produced on board a vehicle (which is unlikely to prove cost effective) or at domestic energy stations then it must be transported close to the point of use and stored in a pressurised tank. The IEA states that a stainless steel network of pipelines is required. It is estimated that the average cost of the pipeline in the US would be $100,000 per km (2005 prices), six times higher than the cost of natural gas pipelines. The alternative is to liquify the hydrogen, and transport it by ship or truck. However, whichever transporting method is used, significant energy penalties are incurred which will have an impact on the energy efficiency of a fuel cell vehicle (FCEV) or other end users for hydrogen. The availability (production) of hydrogen itself would also have to be increased.

Although this report does not specifically address this topics, the existing natural gas pipeline network could be utilised to deliver a mix of hydrogen and natural gas to end use applications as bridging the gap to a hydrogen economy.

### 3.2. Alternative technologies

Although this chapter has largely focused on gas-based applications, there are a range of alternative technologies targeted at the full range of transport modes which aim to reduce emissions of GHGs. The previous sections revealed that the road transport sector (CNG, LNG, hydrogen) and the maritime transport sectors (LNG) are the most suited for the use of gas. Therefore an overview of those alternative technologies aimed at road and maritime transport is provided here (see Appendix 3 for further details on each technology, and those alternative technologies available for the rail and aviation sectors).
Road Transportation Technologies

A summary of key road transport technologies is provided below, including their CO₂ reduction potential. In the short term, there is significant potential for decarbonisation of conventional petrol and diesel powertrains. However, there is likely to be conflict between optimising gasoline and (particularly) diesel powertrains for energy consumption (and hence CO₂ emissions), and optimising for air quality pollutant emissions. In the long term, ultra-low emission options will be needed. The most promising are currently battery electric and hydrogen fuel cell powertrains. However, indirect life-cycle emissions from these technologies would also need to be reduced in the future. There are also a number of drawbacks of using both types of technology that should be taken into consideration. For example, limited range issues and high purchase prices of battery electric vehicles (which are largely due to the battery itself) and the purchase cost, performance, infrastructure provision and fuel cycle for fuel cell vehicles. Neither battery electric vehicles (BEVs) nor fuel cell electric vehicles (FCEVs) are directly comparable to conventional vehicles in terms of price or performance. It is likely that BEVs will initially be most suited to short distance urban vehicles, initially in the light duty sector. Future penetration into the vehicle fleet is highly dependent on battery improvements.

Table 1: Key road transport technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>CO₂ reduction potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Electric Vehicles (BEV)</td>
<td>&lt;40%</td>
</tr>
<tr>
<td>Hybrid Vehicle</td>
<td>10- 25%</td>
</tr>
<tr>
<td>Downsizing with turbocharging</td>
<td>10- 20%</td>
</tr>
<tr>
<td>Variable compression ratio</td>
<td>10%</td>
</tr>
<tr>
<td>Start/Stop</td>
<td>5-10%</td>
</tr>
<tr>
<td>Direct injection</td>
<td>3 – 10%</td>
</tr>
<tr>
<td>Cylinder deactivation</td>
<td>5- 8%</td>
</tr>
<tr>
<td>Variable valve control</td>
<td>7%</td>
</tr>
<tr>
<td>Dual clutch</td>
<td>5%</td>
</tr>
<tr>
<td>Weight reduction</td>
<td>6.5% per 10% weight loss</td>
</tr>
</tbody>
</table>

Source: AEA Technology (2009)

Maritime Transportation

As can be seen in the below table, there are significant options for emissions reduction in shipping. It is possible to retrofit some of these technologies onto existing ships, including kite sails, waste heat recovery, contra-rotating propellers, hull coatings, propeller surface maintenance and air lubrication. However, not all of these technologies can be fitted to all new build designs due to the varying nature of maritime ships. For example, whilst it could be possible to fit wind power to a crude oil tanker, this would not be feasible for a passenger ferry due to the required deck space. Given the long lifetime of maritime shipping, (around 25 to 30 years) it also takes significant time to turn over the existing stock. Apart from LNG, there is very little in terms of powertrain/fuel replacements in maritime transport. However, there are a number of improvements that can be made to existing powertrains for application in new or existing vessels including main engine tuning, common rail technology, turbocharging etc. The majority of improvements in the future will be related to improvements in ship design and operational changes.

Table 2: Key maritime sector technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>CO₂ reduction potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel electric drives</td>
<td>5 - 30%</td>
</tr>
<tr>
<td>Wind power: Flettner rotor</td>
<td>&lt;30%</td>
</tr>
<tr>
<td>Wind Power: Kites and Sails</td>
<td>&lt;20%</td>
</tr>
<tr>
<td>Bulbous bow</td>
<td>&lt;20%</td>
</tr>
<tr>
<td>Air lubrication</td>
<td>&lt;15%</td>
</tr>
<tr>
<td>Counter-rotating propellers</td>
<td>&lt;12%</td>
</tr>
<tr>
<td>Wing thrusters</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Waste heat recovery</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Pulling Thruster</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Topic</td>
<td>Percentage</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Propeller surface maintenance</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Optimum hull dimension</td>
<td>&lt;9%</td>
</tr>
<tr>
<td>Design for reduced ballast operation</td>
<td>&lt;7%</td>
</tr>
<tr>
<td>Lightweight Construction</td>
<td>&lt;7%</td>
</tr>
<tr>
<td>Coatings and Hull Maintenance Strategies</td>
<td>&lt;5%</td>
</tr>
</tbody>
</table>

*Sources: ITF (2009); Wartsila (2009)*
4. Alternative scenario development

An alternative, cost effective, scenario that aimed to meet the EC’s Transport White Paper GHG reduction targets for 2050 (60% by 2050 compared to 1990 levels) was developed and analysed against the BAU and Baseline scenarios. Appendix 4 and 5 detail the assumed split of new vehicle sales and total vehicle stock by mode/powertrain between 2010 and 2050 for this pathway.

4.1. Alternative scenario - road transport sector

Compared with the Baseline scenario (which is primarily focused on technological solutions), the Alternative scenario has identified and utilised the potential for the use of natural gas, particularly in heavy duty power trains. Whilst it is apparent that natural gas (CNG) is currently used in the light duty sector, and has potential for further deployment, legislative requirements (passenger car and van CO$_2$ regulations) mean that ultra-low carbon technologies such as electric and hydrogen fuel-cell vehicles will need to be introduced. The technology-neutral passenger car CO$_2$ regulations have not yet resulted in significant investments in CNG car technology, with the majority of focus being on hybrid technology (petrol/diesel). Similar legislative requirements for heavy duty vehicles do not currently exist, and many low carbon technologies appropriate for light duty vehicles are not feasible in heavy duty vehicles. An increased role of natural gas in this transport segment, therefore, is both feasible and desirable to reduce emissions.

The Alternative scenario does assume some increase in the role of CNG in passenger cars compared with the Baseline. It is likely that deployment will be higher in some Member States than others, as is currently the case. Provision and financing of natural gas refuelling infrastructure is a major challenge that is expected to limit the take-up of CNG cars and vans. It has therefore been assumed that growth will be concentrated in regions where conditions (infrastructure etc.) are particularly favourable, rather than low-level growth in CNG deployment in the light duty vehicle sector across the whole of Europe, which would be inefficient from an infrastructure development perspective. The key to cost-effective deployment of infrastructure is to get maximum possible use from the asset once it is in place. Therefore the Alternative scenario has been developed focussing on growth of CNG use outwards from existing regions of high CNG deployment, rather than diffusing vehicles and infrastructure throughout Europe in low concentrations.

Subsequently, the Alternative scenario places significant emphasis on increasing the role of natural gas primarily in heavy trucks, whilst still achieving the same levels of GHG reduction as in the baseline scenario. It is anticipated that direct CO$_2$ emissions reductions against the 2010 average of 60% will be required for heavy trucks, and 75% for medium trucks; this mirrors reductions in the Baseline scenario. The focus has therefore been on cost-effective replacement of diesel, HEV diesel and hydrogen fuel cell vehicles included in the Baseline scenario with gas powertrains, maintaining the same level of GHG emission reductions. There are a wide range of duty cycles for medium trucks, from urban delivery to inter-urban freight. Some duty cycles, particularly urban delivery, would be better suited to electric or plug-in hybrid powertrains (as the technology matures). CNG (even if hybridised) is not sufficiently low-carbon to meet the emission reductions from the medium truck sector achieved in the baseline on its own (i.e. 75% reduction by 2050, compared to 2010 levels). It has therefore been assumed that a mix of technologies will be used in the long-term.

The main challenge is the cost associated with natural gas refuelling infrastructure and the uncertainties perceived by businesses. Therefore, it is recommended that the focus should be on fleets of vehicles where the refuelling infrastructure is minimal: medium and heavy duty vehicles where refuelling can occur at a limited number of stations, e.g. bus fleets, urban delivery fleets, long distance HDV fleets (refuelling in ‘blue corridors’).

An overview of the Alternative scenario assumptions is provided in Table 3. Full scenario assumptions for new vehicles between 2010 and 2050 can be found in Appendix 5 for the Alternative scenario and Appendix 4 for the Baseline scenario.
<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>A gradually increasing proportion of NGVs in the light duty sector has been assumed. However, in order to be compatible with increasingly stringent GHG emission standards, it is expected that a growing proportion would be hybridised. This is likely to occur later than for gasoline and diesel vehicles, when the marginal costs of both CNG and vehicles and hybrid technology come down. The scenario assumes that regions where there is existing CNG penetration (e.g. Italy, Germany etc.) could see significant growth, but that there will not be large-scale Europe-wide growth. By focusing on specific regions, the overall infrastructure requirements are more modest and retailers can hope to regain their investment more quickly (as infrastructure sees higher utilisation), and start to reduce the margins due to this and increased competitiveness. It is also expected that larger vehicles driving more miles would be more attractive as a CNG option. In the long term, if and when the capital costs of BEVs come down they would be extremely attractive in small urban vehicles. However it would take further performance improvements for BEVs to be suited to larger vehicles. The main barrier to natural gas cars is the cost, and availability, of infrastructure, and the linked issue of gaining consumer confidence that flexibility of travel would not be compromised. A relatively high penetration in a limited number of areas is considered more feasible than a lower penetration over a wider range of geographical regions, because of the infrastructure challenges.</td>
</tr>
<tr>
<td>Vans</td>
<td>Similar issues exist for vans as for passenger cars. However, large, depot-refuelling fleets of vans could be converted to CNG with GHG abatement and cost savings for society and the fleet owners.</td>
</tr>
<tr>
<td>Buses</td>
<td>It is anticipated that there will be significant potential for pure CNG buses due to the potential co-benefits (especially air quality) and the ability to refuel at depots, reducing the infrastructure requirement (although this represents a small proportion of the vehicle fleet). CNG buses appear to be much cheaper than hybrid diesel buses for a broadly similar level of GHG abatement. However, as the costs of hybrid and electric powertrains come down due to technological improvements, the situation may change in the future. At this point, hybridisation may be an option for CNG buses.</td>
</tr>
<tr>
<td>Medium and heavy trucks</td>
<td>It is anticipated that there will be significant potential for CNG and LNG in the heavy trucks sector. They are a particularly attractive option for GHG mitigation in long distance freight, where battery electric vehicles are very unlikely to be feasible, even in the long term, and the costs and technical challenges of hydrogen are very significant. If natural gas vehicles are able to meet EURO air quality pollutant standards at a reduced cost compared with diesel equivalents (as seems likely), this will provide a significant further cost incentive. The attractiveness of these options is likely to depend on a number of conditions: availability of a suitable CNG/LNG supply at a sufficiently low price; a sufficiently large fleet with regular refuelling patterns such that infrastructure needs are low and are well used; and duty cycles that are less suited to hybrid powertrains (e.g. long distance freight).</td>
</tr>
</tbody>
</table>

4.2. Alternative scenario – Inland and maritime shipping sector

With regards to inland and maritime shipping, the Alternative scenario sees an increased use of LNG technology compared with the Baseline. A key benefit to increasing the use of LNG in the maritime sector is that vessels are more likely to meet future IMO specifications for SO2 and NOx emissions (2015 and 2025). Regulation on air quality pollutant emissions will mean that ships will have to either have a scrubber fitted or switch fuel – it is likely that a switch to LNO will be the cheaper option. The uptake of LNG in shipping is only likely to be hindered by the availability of LNG refuelling infrastructure. A sensible penetration rate for LNG in shipping was therefore determined based on the deployment of bunkering infrastructure acting as the limiting factor.1

Scenario work undertaken for this study indicates that the GHG abatement potential of LNG over conventional marine fuel is significant. However, should biofuels be blended with heavy fuel oil to a significant extent this could change, as it is less feasible to introduce biofuel content into LNG bunkers at present. According to a recent study commissioned by the European Maritime Safety Agency,17 blends of up to 20% biodiesel into heavy fuel oil could be used in existing ships with no modifications. Higher blends

would require some engine modifications, but for new ships it is possible to replace heavy fuel oil with, for example, vegetable oil with some engine adaptation. In the case of LNG, the report cites technical and organisational challenges with sourcing and transporting sufficient bio-LNG to feed into major LNG terminals. This is an important concern since recent analysis for the Commission\textsuperscript{8} suggests that it is very likely that significant biofuel penetration into shipping fuels will be needed in order to meet 2050 targets for GHG reductions from maritime shipping.

\textsuperscript{8} EU Transport GHG: Routes to 2050. http://www.eutransportghg2050.eu/cms/
5. Scenario analysis results - Economic and other policy implications of pathways

One of the primary objectives of this study was to identify a potential alternative scenario which not only met the EC’s GHG reduction targets for 2050, but also did so in a cost effective manner. This section sets out the key results from the SULTAN analysis for the Baseline and Alternative scenarios. This includes meeting GHG emission reduction targets, energy consumption, costs of GHG abatement, cost effectiveness, and impacts on air pollutant emissions. Supporting data tables can be found in Appendix 6.

5.1. Meeting greenhouse gas (GHG) emission reduction targets

Both scenarios have been designed to meet the EC Transport White Paper target for 2050, a 60% reduction in GHG emissions by 2050 compared with 1990 levels. Figure 6 below shows how each scenario achieves this over the period 2010 to 2050. As the figure shows, the Baseline and Alternative scenarios follow the same GHG reduction trajectory. In 2030, GHG emissions are 1,208.1 MtCO$_2$e for the Alternative scenario (White Paper target is 1,331.1MtCO$_2$e); and in 2050 it is 538.5 MtCO$_2$e (White Paper target is 544.5 MtCO$_2$e).

Figure 6: Total combined (lifecycle) GHG emissions – Baseline and Alternative scenarios

As with any long-range analysis, uncertainties in future technological and price developments increase in the later time period. In particular, beyond 2030 it is more difficult to predict the cost and performance of as yet unproven technologies, and the future evolution of energy markets in the context of significant global change. Our analysis and assumptions reflect the latest understanding of likely future developments and, where available, are consistent with European Commission assumptions.

5.2. Energy consumption

The energy consumed in the transport sector (by energy carrier) for the Baseline and Alternative scenarios is shown in Figure 7. Compared with the Baseline, the Alternative scenario primarily demonstrates an increase in natural gas (notably LNG) and a reduction in energy consumed from gasoline (-5%), diesel (-13%) and marine fuels (-30%). There is also a decrease in the consumption of hydrogen (-14%), and the consumption of electricity is virtually unchanged. There still remains a diverse use of fuels in both scenarios.
It is evident that substantially more gas is consumed in the Alternative scenario compared to the baseline – 512 TWh in 2050, compared to 106 TWh for the Baseline in the same year (CNG and LNG combined) (see Figure 8).

Figure 9 shows the consumption of natural gas by transport mode in 2030 and 2050. Whilst there are increases for all modes, the most significant increases can be found in the heavy truck and maritime shipping segments.
In terms of percentage of energy consumption, natural gas (CNG/LNG) accounts for 3.4% in the Baseline in 2050 compared to 16.3% for the Alternative scenario (see Table 4).

Table 4: Percentage gas use (CNG/LNG) in Baseline and Alternative scenarios

<table>
<thead>
<tr>
<th>NG</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
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</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.2%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.5%</td>
<td>0.8%</td>
<td>1.3%</td>
<td>1.9%</td>
<td>2.6%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Alternative</td>
<td>0.2%</td>
<td>0.3%</td>
<td>0.6%</td>
<td>1.5%</td>
<td>3.3%</td>
<td>5.6%</td>
<td>8.6%</td>
<td>12.4%</td>
<td>16.4%</td>
</tr>
</tbody>
</table>

Combined, the Alternative scenario assumes that almost triple the amount of CNG (100% attributable to road transport) and close to eight times the amount of LNG (the majority of which has been attributed to shipping) is deployed in the transport sector in 2050 compared with the Baseline scenario. The assumed increased consumption of natural gas can largely be attributed to changes in the heavy truck and maritime shipping transport sectors (with more modest increases for other modes of transport) the consumption of natural gas in the bus sector also increases substantially, but has a modest overall impact because of the size of the segment.

5.3. Cost of GHG abatement and cost effectiveness

The cost of abatement associated with the Alternative scenario compared with the Baseline scenario is demonstrated in Figure 10.10 Vehicle production and disposal emissions have not been included within the analysis. For road modes, the literature suggests that these are likely to be higher for electric powertrains than conventional combustion engines. Including this in a full life cycle view is likely to make natural gas powertrains more attractive from a GHG reduction perspective, although further analysis would be required to examine how significant this would be.

10 In view of the relevant uncertainties surrounding the eventual cost performance of the two technologies, similar levels of EV and FCEV vehicle deployment have been kept, and the relative levels of deployment between the two the Baseline and the Alternative scenarios have not been changed. FCEV technology appears significantly more expensive than EV technology based on the current results in the
shipping are all anticipated to achieve cost savings in the Alternative scenario compared with the Baseline. In total, savings of €68 to €77 billion are anticipated to be achieved, which demonstrates a clear financial benefit over the Baseline scenario. Cost savings can largely be attributed to the heavy truck and maritime shipping sectors. Heavy trucks are anticipated to achieve cost savings of €35-40 billion by 2050 (depending on the fuel price assumptions), whereas maritime shipping is anticipated to achieve a cost saving of €25 billion. Buses also make a modest contribution to the overall cost savings, of €8-11 billion.

The cost effectiveness to society of reducing GHG emissions using various low carbon transport technologies has also been explored (i.e. cost per tonne of CO\textsubscript{2}e saved). Appendix 7 shows the cost effectiveness of a range of technologies for each transport mode in the Alternative scenario. This analysis has been based on the high fuel price scenario, and shows cost effectiveness to society (2010 €/tCO\textsubscript{2eq}) in the years 2010, 2030 and 2050 for each mode/powertrain.

\textbf{Figure 10: Cost savings associated with the Alternative scenario compared with the Baseline in 2050 (€billion, present value in 2010)}

The largest cost savings are anticipated in the next 20 years, up to 2030 (see Figure 11). The savings in the period 2030 to 2050 are less pronounced, as very low-carbon technologies are required to meet more stringent GHG reduction targets, and the costs for as yet unproven technologies are expected to decline. Cost savings in the period 2010 to 2030 are likely to be in the region of \textbf{€58 to €67 billion}. Cost savings between 2030 and 2050 are estimated to be a further €10 billion.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{cost_savings.png}
\caption{Cost savings associated with the Alternative scenario compared with the Baseline in 2050 (€billion, present value in 2010)}
\end{figure}

SULTAN analysis. In all of the modes where it features, FCEV vehicles are by far the least cost-effective technology option until late in the time series (2040 onwards).

\footnote{The cost of abatement in the Alternative scenario is €26,809 billion compared with €26,871 billion for the Baseline (CPI price projections).}
Figure 11: Cost savings associated with the Alternative scenario compared with the baseline to 2030 and to 2050 (€ billion, present value in 2010)

Key messages regarding cost savings achieved in the Alternative scenario compared with the Baseline are outlined below.

Passenger cars are anticipated to achieve modest cost savings compared with the Baseline (between €0.4 and €1.4 billion).

- The different technologies covered in the scenarios are not like-for-like replacements and will be best suited to different duty cycles:
  - Hybrid and electric powertrains have potential for small urban vehicles operating under stop/start traffic conditions, where regenerative braking helps to improve energy efficiency and the low range of batteries is less of an issue.
  - For larger vehicles travelling longer distances, there is greater potential for CNG (scenario modelling uses ‘average’ vehicles and is therefore not sufficiently detailed to reflect this), and increased cost savings.

Buses are anticipated to achieve relatively moderate cost savings of €8-11bn.

- Analysis indicates that CNG is the most cost-effective abatement option for buses throughout the time period (until the 2040s, when the falling capital cost of EVs means they become very cost-effective).
- Analysis also indicates that, when lower emitting technologies become necessary to further reduce GHG emissions, HEV-CNG buses would have a higher abatement potential than HEV diesel buses.
- According to the fuel price analysis, the ability to refuel a large number of vehicles at a single site and use the infrastructure intensively (e.g. at a depot) changes the economics of natural gas vehicles, because it allows intensive use of infrastructure and high volume supply contracts to be negotiated with the CNG provider. This applies to buses and trucks. Therefore these situations should be targeted for natural gas vehicles.
- Deploying more CNG and HEV-CNG buses in the short and medium term means less potentially expensive technologies are needed (such as EVs and FCEVs) than if only diesel HEV buses are used (as in the baseline).
- For large, longer distance bus duty cycles in inter-urban operation involving less stop-start operation, CNG would seem better suited than HEV diesel vehicles and may remain so.
- Buses are most commonly used in areas of high population density, and as such areas often also have a good gas supply, supply of gas is unlikely to be a barrier to adoption.

In the heavy truck segment the highest potential cost savings (€30-40bn, amounting to savings of 1.5-2%) are anticipated to be achievable.

- There are limited decarbonisation technology options in the heavy trucking sector, particularly for long-distance haulage, where hybridisation is less effective (due to less stop/start operation) and battery electric vehicles are highly unlikely to be feasible. In addition, there is an opportunity for dual
fuel technology to be deployed. This allows higher compression ratios, and hence a higher efficiency of operation, than a spark-ignition engine running on natural gas. This further improves the GHG savings from natural gas vehicles in the heavy truck segment. Some technical and regulatory barriers need to be overcome to bring dual fuel vehicles to the mass market, however.

- The analysis suggests that as the capital cost of natural gas technologies in the heavy truck segment declines in the long term (due to anticipated technological improvements and economies of scale), the total vehicle lifetime costs (capital and operating costs) will decline to below that of a conventional diesel vehicle. This assumes that refuelling infrastructure is in place and is used intensively (e.g. in blue corridors).
- Even in the short term, CNG vehicles appear the most cost-effective form of abatement (though they offer only modest GHG savings compared with diesel vehicles). LNG appears less cost-effective, but is much more suitable for long-distance duty cycles than CNG or hybrid-electric technologies.
- Deploying more natural gas vehicles in the short and medium term means less potentially expensive technologies (such as FCEVs) are needed to achieve the overall GHG emissions reduction targets, resulting in overall cost savings.

Inland shipping is anticipated to see a modest cost saving of €0.2 to €0.3 billion in the Alternative scenario compared to the Baseline.

- In all years, LNG appears desirable from an economic point of view, so it could be expected that deployment may only be limited by the availability of refuelling infrastructure and inertia within the industry holding up adoption of new engine types in new build ships.

Maritime shipping is anticipated to achieve cost savings in the Alternative scenario of around €25bn under both fuel price scenarios.\(^\text{12}\)

- The Alternative scenario results in both cost and GHG emission reductions compared with the Baseline in maritime shipping – GHG emission reductions are in the order of 10 MtCO\(_2\) in 2050, or a 6.6% reduction.
- Analysis shows LNG in maritime shipping to be both cheaper over the lifetime of a vessel, and lower in emissions – so it would be expected that operators would take up this option even if not compelled by GHG regulation. This assumes that forthcoming fuel quality legislation means that conventional ships using high-sulphur heavy fuel oil will need either exhaust scrubbers fitted, or to use a more expensive refined fuel (e.g. marine diesel oil) in order to comply – or move to using LNG.
- It is possible that uptake of LNG would be initially limited by availability of refuelling infrastructure and inertia within the industry leading to reluctance to move to new engine technologies. An important point to note with maritime shipping is the issue of split incentives - the operator is often not the same entity as the ship owner, meaning the party that has to make the investment (in more expensive LNG technology) is not the same party that benefits from the reduced fuel operating costs.
- This study assumes that biofuels are blended extensively with both marine bunker fuel (heavy fuel oil) and marine bunker LNG. Barriers currently exist in the injection of bio-LNG into LNG bunkers that would need to be overcome. In the absence of biofuels, the 2050 target for maritime shipping cannot be reached without further operational measures, e.g. more energy efficient vessels, reduced shipping volumes.

Vans and medium trucks are not anticipated to see significant cost savings in the Alternative scenario compared to the Baseline scenario.

## 5.4. Impact on air pollutant emissions

Reductions in a range of air pollutants have been identified as a key co-benefit of using natural gas in the transport sector (see Chapter 3). The greatest benefit in terms of air pollutant emission reductions in the Alternative scenario can be seen in the shipping sector. In total, shipping is expected to see a 12% reduction in PM emissions and 2.5% reduction in NO\(_x\) emissions in 2050 compared to the baseline (maritime shipping is expected to see reductions of 19% for PM and 5% for NO\(_x\)). For the majority of road

\(^{12}\) Cost savings anticipated to be similar under both scenarios because the decision is between two fossil fuels using engines of a similar efficiency, and the relative prices of the two fuels do not change significantly between the two scenarios (i.e. in the low price scenario, both fuels reduce in price by roughly the same amount).
transport modes, it can be expected that there would be modest reductions or neutral effects for PM and NOx in the Alternative scenario compared with the Baseline, with the exception of buses. This is because new European exhaust emissions standards are expected to result in significant reductions in emissions of air quality pollutants from new vehicles in the future. In addition, improved fuel efficiency due to hybridisation and other measures would further reduce pollutant emissions by reducing the amount of fuel burnt. However, this assumes that real-world vehicle performance broadly reflects test cycle performance – currently there is a significant disparity in many vehicles, which undermines the effectiveness of emission standards.

For passenger cars a slight improvement in PM and NOx emissions has been anticipated in the Alternative scenario compared with the Baseline, as CNG is a much cleaner fuel than diesel. This is offset to an extent by the reduced fuel consumption of hybrid technologies (which offer similar levels of GHG abatement). Coupled with the incoming legislation on emissions of air pollutants, all vehicles are expected to have very low air pollutant emissions. This is likely to result in a slightly higher cost to manufacture and slightly higher fuel consumption than if the legislation were not in place (which has been factored into the SULTAN inputs). Therefore the result is that hybrid technologies have similarly low emissions of PM and NOx compared with natural gas vehicles in the medium term. As mentioned earlier, inland shipping and maritime shipping are also anticipated to see improvements in emissions of PM and NOx.

However, for buses potential increases in PM and NOx by 2050 under the Alternative scenario could be due to the primary energy consumption increasing as natural gas powertrains are generally less energy efficient than hybrid or electric powertrains (for similar GHG and air pollutant emissions). Primary energy consumption is up around 20% in 2050 in the Alternative scenario compared with the Baseline. This also leads to an increase of a similar degree of air quality pollutants against the baseline. However, there are still very significant savings in air pollutants to be gained through the natural gas scenario (compared to business as usual), with emissions from buses in 2050 one fifth of the levels in 2010.
6. Policy Implications and Recommendations

This study has considered an Alternative pathway to achieving European GHG reduction targets for 2050 in the transport sector. Analysis of this Alternative scenario compared with the Baseline has revealed that it is possible to meet these targets in 2050 in a more cost-effective manner. In particular, the analysis revealed potential cost savings in the order of €68 to €80 billion through selecting the Alternative scenario compared with the Baseline (depending on fuel price assumption used). By mode, these cost savings are as follows:

- Heavy trucks: €35 to €40 billion;
- Maritime shipping: €25 billion;
- Buses: €8 to €11 billion;
- Passenger cars: €0.4 to €1.4 billion; and
- Inland shipping: €0.2 to €0.3 billion.

In addition to cost savings, analysis revealed that the Alternative scenario could potentially achieve air pollutant reduction benefits compared to the Baseline, particularly in the maritime shipping sector (12% reduction in PM emissions and 2.5% reduction of NOx emissions in 2050).

Recognition should be given to the important role that natural gas can play in the transition to a low carbon economy and the on-going role of gaseous fuels in a long term European low carbon transport system, as demonstrated through the Alternative scenario\(^\text{13}\). The results shown in the Alternative scenario reinforce those of the Forum’s previous study – “Making the Green Journey Work” – in that continuing the use of gas is consistent with long term decarbonisation goals and provides economic benefits, something which is also echoed in the Forum’s study on the residential sector.

This study also identified a number of potential barriers to successful uptake of the Alternative scenario. These include the widespread availability/provision of refuelling infrastructure for natural gas vehicles; natural gas vehicle purchase prices; overall lifecycle economics of owning a gas-fuelled vehicle, and current consumer and business attitudes towards the purchase and use of natural gas vehicles. Market barriers also exist, particularly in the segments that have been identified as being key to delivering the main benefits of the Alternative scenario. In the maritime shipping segment, there is the issue of split incentives, whereby the ship operator is often not the same entity as the ship owner, and therefore the party that has to make the investment (in more expensive LNG technology) is not the same party that benefits from the reduced fuel bill. In the heavy trucks segment, the lack of consumer confidence into the benefits that natural gas use could bring is a barrier, together with consumer concerns about the availability of refuelling infrastructure.

Therefore, in order to achieve the potentially considerable cost savings in Europe as outlined in the Alternative scenario, such potential barriers and challenges need to be overcome\(^\text{14}\). This could be achieved through implementing a range of policy measures, which are either aimed at stimulating natural gas in the transportation sector (but are currently implemented in few Member States), or that currently exist for alternative technologies but could be adapted towards natural gas. Such options include fiscal measures, technology-support measures, measures aimed at stimulating the use of alternative fuels more widely, the provision of appropriate gas-based infrastructure, the introduction of vehicle-specific performance targets or standards, and measures aimed at improving air quality. It is recommended that further research is undertaken into potential policy measures and how they should be implemented in the EU to achieve the desired results. Measures to be considered with the greatest potential are outlined below:

\(^{13}\) 512TWh gas consumed in the Alternative scenario in 2050 compared with 106TWh in the Baseline.

\(^{14}\) Barriers would also need to be overcome in order to achieve the Baseline scenario. For example, provision of battery recharging infrastructure for electric vehicles.
In order to promote the use of natural gas ships, the most successful policy measures are likely to include those aimed at increasing the number and emission limits of Emission Control Areas (ECAs).

Measures aimed at incentivising the provision of natural gas refuelling infrastructure should be considered (equivalent measures for other low carbon transport technologies include, for example, the UK’s ‘Plugged-in Places Programme’, which supports the introduction of recharging infrastructure for electric vehicles). This could include allocating specific funding for the development of public natural gas refuelling infrastructure and subsidised loans/grants for the development of private natural gas refuelling infrastructure. Recent support for European LNG ‘blue corridor’ projects are a welcome move in this direction.

Through the introduction of vehicle purchase/substitution subsidies, and subsidised loans for the purchase of natural gas trucks (or their conversion), economic barriers to the purchase of natural gas vehicles could be removed.

The introduction of technology-support measures (incentives directed towards specific vehicle technologies, including natural gas vehicle technology) would help to reduce barriers related to natural gas vehicle availability.

Taxation-based measures, such as reduced taxation schemes for natural gas fuels, tax benefit schemes for vehicles and company car reduced income tax schemes could contribute to ensuring running costs associated with natural gas vehicles remain attractive.
References


IEA (2010a) Automotive hydrogen technology. IEA ESTAP Technology Brief T07


Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>BAU</td>
<td>Business as Usual</td>
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<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
</tr>
<tr>
<td>CPI</td>
<td>Current Policy Initiative</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
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<td>EC</td>
<td>European Commission</td>
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<td>ECA</td>
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<td>Hybrid Electric Vehicle</td>
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<td>Internal Combustion Engine</td>
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<td>International Energy Agency</td>
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<td>LDVs</td>
<td>Light Duty Vehicles</td>
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<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
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<td>Nitrogen Oxides</td>
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<td>Original Equipment Manufacturer</td>
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<td>PHEV</td>
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<td>Particulate Matter</td>
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<td>United Nations Framework Convention on Climate Change</td>
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