European
Commission

State of the Art on Alternative Fuels Transport Systems in the European Union

FINAL REPORT

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1 Introduction

It is expected that alternative fuels will play a more and more prominent role in the decade to come in view of the EU objectives of gradually substituting fossil fuels with fuels of renewable origin, growth and jobs, competitiveness, transport decarbonisation and the diversification of the energy sources. However, there is currently a lack of attractiveness of fuel alternatives for consumers and businesses, and no clear market signals with regards to the potential of the different new alternative fuels. For instance, alternative fuel vehicles only represented 3.4% of the European car fleet in 2012 and the use of alternative fuels in heavy duty vehicles and maritime and aviation modes is negligible.

The Commission established in March 2010 a stakeholder Expert Group on Future Transport Fuels (EG FTF), with the objective of providing advice to the Commission on the development of political strategies and specific actions aiming to the substitution of fossil oil as transport fuel in the long term, and decarbonising transport, while allowing for economic growth.

The first report from the Group on the "Future transport Fuels", issued in January 2011, stated that alternative fuels are the ultimate solution to decarbonise transport, by gradually substituting fossil energy sources. There is no single candidate for fuel substitution. Fuel demand and greenhouse gas challenges will most likely require the use of a mix of fuels, which can be produced from a large variety of primary energy sources. There is broad agreement that all sustainable fuels will be needed to fully meet the expected demand. Different modes of transport require different alternative fuel options".

The second report from the Group on "Infrastructures for alternative fuels" issued in December 2011 stated that the current lack of an EU-wide alternative fuel infrastructure prevents the market uptake for most alternative fuels in transport systems for certain fuel alternatives. Therefore an appropriate EU regulatory framework and financial instruments are required to further support such alternative fuels and give European citizen a choice for clean transport, in the same way as it has been essential to bring renewable energy production to today's market share. With this said it should however, be emphasised that a number of the alternative fuels do not require new and/or expensive infrastructure. The key need for introduction of renewable fuels is long term stable legislation, which gives economic incentives to the fuel production until they have reached a point where they can compete with fossil alternatives.

Both reports were the grounds of the "Clean Power for Transport package" adopted by the European Commission on 24 January 2014, which is constituted by a Communication laying out a comprehensive alternative fuels strategy for the long-term substitution of oil as energy source for transport, and a proposal of Directive on the deployment of alternative fuels infrastructures and a staff working document on an LNG Action Plan for shipping.

The Directive 2014/94/EU on the deployment of alternative fuels infrastructures was adopted by the European Parliament and by the European Council on 22 October 2014. The Directive sets minimum requirements for the infrastructure build-up, including common technical specifications. It also foresees fuel labelling at refuelling points and on vehicles, to ensure consumer information as regards the compatibility between fuels and vehicles. Member States (MS) will have the obligation to develop National Policy Frameworks for the market development of alternative fuels infrastructure, and set their own targets and objectives, adapted to their national context.

The present report, based on the contributions of the EG FTF, has the main objective to provide an update of the latest developments in the field of alternative fuels and the market uptake of alternative fuel transport systems and related infrastructure in the EU. This information, among the other guidance documents elaborated by the Commission, will be of good assistance to MS to prepare their National Policy Frameworks. The report also contains some recommendations to MS to facilitate the achievement of the objectives of the Directive as well as to the Commission to pursue a further market uptake of alternative fuel transport systems in the EU.

1.1 Aim of the report

The aim of the study is to gather information of the development of alternative fuels for transport in the EU and to give a broad overview.

The report encompasses the facts, the figures and the positions of the Expert Group on Future Transport Fuels (EGFTF) on the measures (policy and research) to be taken to ensure the proper development of alternative fuels in the EU. It has been drafted by COWI mainly on the basis of the results of the meetings of the Expert Group of future transport fuels as well as on further information provided by the members of the Group.

2 Current EU transport fuel supply and projections

EU transport was responsible for 32% of final energy consumption (352 Mtoe) in 2012[1] (Figure 2-1). Adding maritime bunker fuels, energy used in transport totalled about 398 Mtoe2.

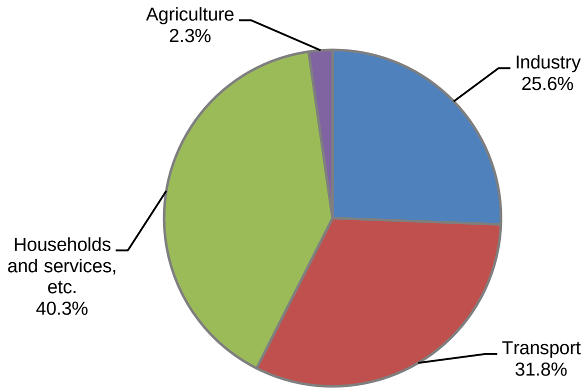

Figure 2-1: Final Energy Consumption, by sector (EU28)

When looking at total EU transport energy demand Figure 2-2), covering domestic, intra-EU and intercontinental traffic, road transport is by far the largest energy consumer (72.3% of the total). Aviation is the second largest consumer with a share of 12.4%, followed by international maritime transport (11.5%). Rail transport accounts for 1.8% (60% of which is used for electric traction), and finally inland navigation consumes only 1.1%[3.]

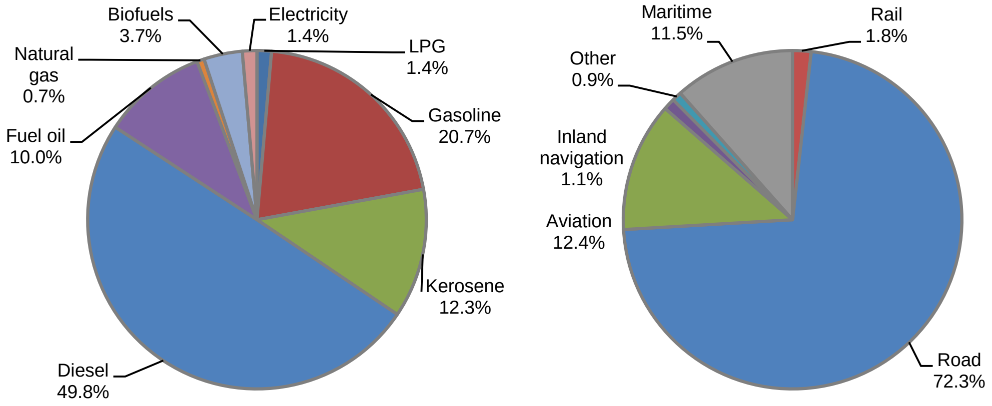

Figure 2-2: Share of transport energy demand by source and mode in 2012 (%)

In 2012, EU transport depended on oil products for about 94% of its energy needs Figure 2-2). Europe imports around 86% of its crude oil and oil products from abroad, with a bill up to EUR 1 billion per day.

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[1] Final energy consumption covers energy use in industry, transport, residential and services, agriculture and fishing. For transport, it includes energy use in road, rail, aviation (domestic and international), domestic navigation (inland waterways and national maritime), pipeline transport and other. International maritime (bunker fuels) is outside the scope of final energy consumption.

[2] Source: Eurostat

[3] Source: Eurostat

Strong efforts would be required to drastically reduce the oil dependency and the greenhouse gas (GHG) emissions in the transport sector, in line with the goals put forward in the 2011 White Paper on Transport, i.e. a 20% reduction in the GHG emissions by 2030 relative to 2008 levels and a 60% reduction by 2050 relative to 1990 levels.

Transport dependence on oil not only needs to be reduced, but the energy sources also need to be diversified. Almost all energy consumed in air and waterborne transport was petroleum-based in 2012. Road transport depended on oil products for 94% of its energy use and rail transport for about 40%. Air transport is most dependent on oil, with the main alternative energy source being biomass. For road and waterborne (maritime and inland waterways) applications some possible alternatives exist, such as, biomass, other renewables and nuclear power (via electricity and hydrogen production) and possibly for a transition period other fossil resources (e.g. LNG and GTL).[4] However, in the long term, most fuels would need to be of non-fossil origin in order to secure a reduction in GHG emissions. For international maritime shipping, LNG can play an important role as it is available in considerable amounts This technology, however, needs to overcome substantial technical, distribution and financial barriers before a large-scale uptake is feasible. Other alternatives are marina gas oil (MGO) and methanol. For short sea shipping there is also some potential in hybridisation and electrification. For road, many energy sources could be used for different types of vehicles, including vehicles powered by the most common internal combustion engines, by hybrid propulsion in a combination of internal combustion engines and electric motors, fuel cells combined with an electric motor, and battery supplied electric vehicles. For rail, the main alternative energy sources are electricity and biomass.

Under current trends and adopted policies by the end of 2013, oil is expected to stay the main energy source for transport in the medium to long term, although declining to some extent in future years (see Figure 2-3).

Oil products would still represent about 88% of the EU transport sector needs in 2030 and 84% in 2050, despite the fact that the deployment of alternative fuels infrastructure supports substitution effects towards electricity, hydrogen and natural gas.

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[4] Some relevant liquid fuels blend-stocks currently used, although of fossil origin, are actually crude-oil alternative. An example are fuel-ethers, which are manufactured out of methanol and butylene in turn starting from field gas.

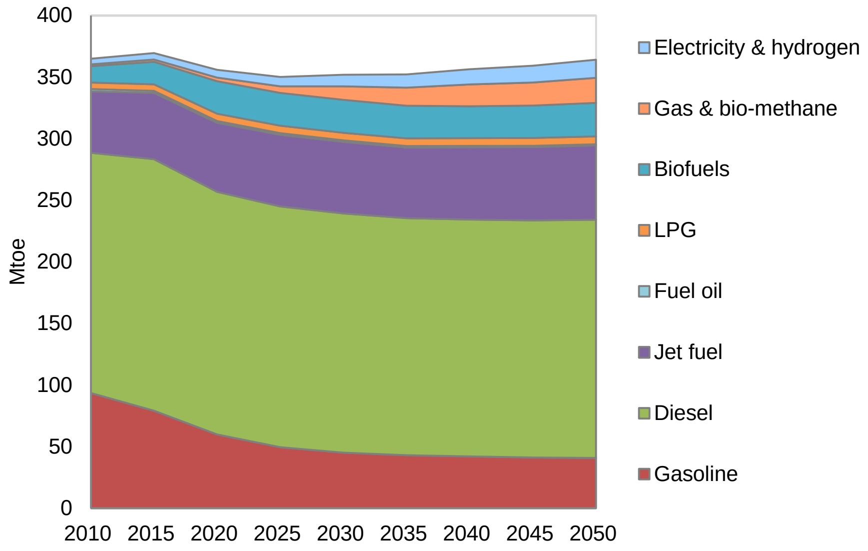

Figure 2-3: Final energy use in transport under current trends and adopted policies. Source: Source: Reference+ scenario, PRIMES-TREMOVE model, E3M-Lab (ICCS/NTUA)[5]

Electricity use is expected to increase steadily as a result of further rail electrification and the uptake of alternative powertrains in road transport. Driven by EU and national policies as well as incentives schemes, electrically chargeable vehicles (battery electric and plug-in hybrid electric vehicles) are expected to see a faster growth beyond 2020 in particular in the segment of light duty vehicles[6]. Due to improvements in battery costs, capacity and increased availability of recharging infrastructure, the limited range of battery electric vehicles (BEV) is thus becoming less of a constraint to their use already today and will continue to do so in the years to come. The deployment of fast charging infrastructure would also facilitate long distance trips. The share of electrically chargeable vehicles in the total stock of light duty vehicles would reach about 4% by 2030 and 9% by 2050.7 The uptake of hydrogen would be facilitated by the increased availability of hydrogen refuelling infrastructure, but its use would remain limited by 2050 in lack of policies adopted beyond the end of 2013. Fuel cells would represent slightly more than 1% of the light duty vehicle stock by 2050[8].

Nevertheless, technologies like electronics, ICT and lithium batteries have evolved faster than anticipated the last few years, and these promising trends will continue to further change the vision on electromobility. According to Euroelectric, on a total cost of ownership, BEVs and PHEVs can already be more attractive than their internal combustion equivalent, including current subsidies, mainly due to cost savings on fuel and lower maintenance costs.

The share of liquid and gaseous biofuels is expected to increase by 2020, driven by the target of 10% renewables energy in transport, although trade barriers to, in particular, cross border supply of biofuels should be monitored and eliminated in order

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[5] The projections under current trends and adopted policies with a cut-off date end of 2013 (so-called Reference+ scenario) draw on the EU Reference scenario 2013, but include some additional policies adopted at EU level by the end of 2013 (e.g. Clean Power for Transport Package). No additional policies are assumed beyond the end of 2013 but the policies in place are implemented beyond this cut-off point. The so-called Reference+ scenario has been developed with the PRIMES-TREMOVE model by E3M-Lab (ICCS/NTUA). A detailed description of the EU Reference scenario 2013 is available at: http://ec.europa.eu/transport/media/publications/doc/trends-to-2050-update-2013.pdf

[6] Light duty vehicles include passenger cars and light commercial vehicles.

[7] Source: Reference+ scenario, PRIMES-TREMOVE model, E3M-Lab (ICCS/NTUA).

[8] Source: Reference+ scenario, PRIMES-TREMOVE model, E3M-Lab (ICCS/NTUA).

for biofuels to reach their full market potential. In lack of other policies adopted beyond the end of 2013, biofuels would maintain their share in the medium to long term. However, with additional incentives in place the share of biofuels may continue to increase, resulting in improved economics of biofuel supply. The proposals planned under the Energy Union strategy may trigger such expansion of biofuels after 2020. Natural gas (in the form of CNG and LNG) is increasingly used in road passenger, freight and waterborne transport from 2020, facilitated by the availability of refuelling infrastructure. Natural gas (and biomethane) vehicles may become an important technology due to improved air quality and CO_2 performance, especially when blended with biomethane,

The EU's Climate and Energy Package, as well as the recently published Energy Union Roadmap could trigger further expansion of alternative fuels, including biofuels, electricity, natural gas and other clean fuels as it supports further steps to decarbonise transport and reduce the sector's dependence on oil.

The use of oil is one of the main contributors to greenhouse gas (GHG) emissions. Under current trends and adopted policies by the end of 2013, CO2 emissions from transport (excluding international maritime) would go down by about 8% between 2010 and 2050 mainly driven by fuel efficiency gains due to CO2 standards for light duty vehicles and increasing fossil fuel prices9. Major decreases in carbon intensity of energy use in transport are expected to be less pronounced in the medium to long term, in lack of policies adopted beyond end of 2013.

Figure 2-4 provides a comparison of the final energy use in transport under current trends and adopted policies by the end of 2013 and under a scenario achieving 60% GHG emissions reduction by 2050 in line with the ambitious goal put forward in the 2011 White Paper. To achieve large GHG emissions reductions, electricity, hydrogen and biofuels would make significant inroads in final energy demand by 2050.

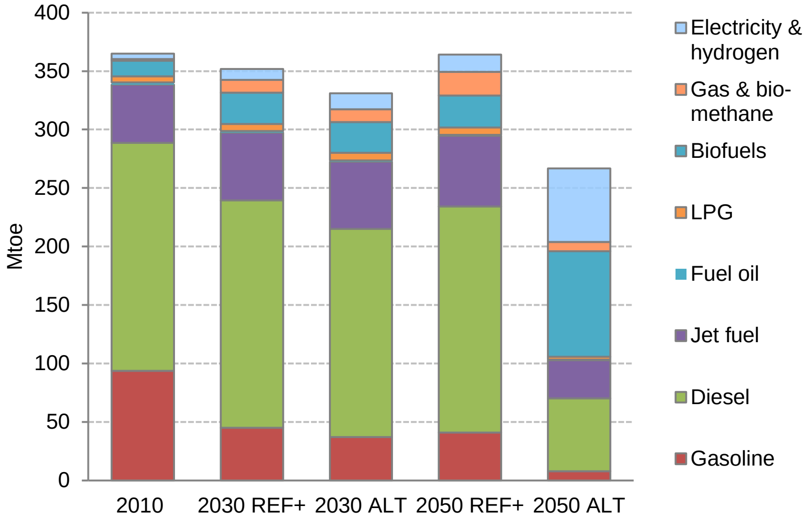

Figure 2-4: Final energy use in land transport under current trends and adopted policies and under an alternative scenario achieving 60% GHG emissions reduction by 2050, EU28[10]

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[9] Source: Reference+ scenario, PRIMES-TREMOVE model, E3M-Lab (ICCS/NTUA).

[10] Note: REF+ stands for the Reference+ scenario, providing projections under current trends and adopted policies by the end of 2013 and ALT stands for an alternative scenario achieving a 60% GHG emissions reduction by 2050, in line with the goal put forward in the 2011 White Paper. The projections have been developed with the PRIMES-TREMOVE model by E3M-Lab (ICCS/NTUA).

Another study, conducted for the European Climate Foundation11, shows that large deployment of clean fuels in transport could significantly shift spending from imported fossil fuels towards the European manufacturing industry. In scenarios in which Europe moves rapidly to a fleet of advanced hybrid, battery electric and fuel cell vehicles, the fuel bill for the car and van fleet is reduced by 58-83 billion EUR in 2030, CO_2 emissions are cut significantly - supporting established targets for 2030/2050 - and air quality significantly improved.

If shipping emissions were to be reconciled with a 2° global warming target, substantial reductions would also be needed in this sector. Such measures are however best addressed at global level.

Reducing the oil dependence by diversifying into alternatives is a major challenge for transport. However, developing innovative and ever cleaner alternative fuels is also a way to make Europe's economy more resource-efficient. It brings great achievements in research and technological development to fruition in the market, with benefits for both industry and society. Success remains nevertheless dependent on major technological breakthroughs and customer acceptance. In this major shift of primary energy sourcing it is also important to avoid the development of new energy dependence, not the least to avoid new fossil based systems.

Achieving the 60% reduction in transport GHG emissions by 2050 is a very challenging task that will require a gradual transformation of the entire transport system towards greater integration between modes, innovation and deployment of alternative fuels, and improved management of traffic flows through intelligent transport systems.

The smart use of alternative fuels in the transport sector can provide multiple benefits in terms of security of supply, reduction of GHG (and noxious) emissions, air pollution and overall sustainability. The potential of a fuel candidate to make significant inroads into the market depends on several elements like e.g. the availability of potential feedstock and the complexity of the production process, the compatibility with engine technologies and distribution infrastructure, and the GHG savings potential. Invariably, the introduction of alternative fuels is coupled with the development and implementation of advanced, fuel-flexible combustion modes that can better exploit their properties. However, as some of the related engine technologies are still at lower technology readiness levels, this will require significant research efforts.

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[11] Cambridge Econometrics (2013) Fuelling Europe's future. How auto innovation lead to EU jobs. http://www.camecon.com/Libraries/Downloadable_Files/Fuelling_Europe_s_Future-_How_auto_innovation_leads_to_EU_jobs.sflb.ashx

3 Elements used to analyse the situations of the different fuels

The evaluation is structured per fuel type, splitting analysis between fuel production (Chapter 4) and the use of fuels in transport sectors (Chapter 5). Chapter 4 covers greenhouse gas (GHG) emissions and energy efficiency. It further looks at the different pathways for producing the fuels, the potential supply of these fuels and the maturity of the development of these fuels to the transport sector. However, the infrastructure needed to deliver the fuels to the vehicles or vessels is not included in Chapter 4 as part of the production/supply side, but is included in Chapter 5. Moreover, the production costs of the fuels are covered in Chapter 4. Chapter 5 is also structured so that a section is dedicated to each different fuel, but focus is on the use of the fuels. Chapter 5 thus considers the maturity of the infrastructure and the vehicles and vessels using the different fuels, the costs related to infrastructure and vehicles, but does not consider e.g. total cost of ownership. The current market status and the future potential of the fuels in different transport markets are outlined.

Although not all analysis aspects are equally relevant or important for each fuel, most of the analysis criteria are covered for all fuels. Moreover, the experiences with different fuels and information about the evaluation criteria vary. This also applies to data availability and reliability, which influence the possibility of presenting alternatives and information. Hence, there are also variations in the information presented for each fuel.

3.1 Elements for description of fuels

The different elements covered in Chapter 4 for each of the fuels are:

- **DEFINITION AND OVERALL DESCRIPTION.** What characterizes the fuel? A short general description of the fuel and its uses in the transport sector is given. Details on the use of the fuels are provided in Chapter 5.
- **AVAILABILITY AND POTENTIAL PRODUCTION CAPACITY.** An assessment of the annual production capacity of the specific fuels and of the development trend in the short (2020), medium (2030) and long term (2050) of the fuel is given. Different sources for assessing this are available (e.g. World Energy Outlook), Information has been collected from a variety of sources provided by the EGFTF, but in some cases there are not usable sources found to cover all details.
- **GHG EMISSIONS.** What are the expected GHG reductions? The assessments use the JEC Wells-to-wheels report (JEC 2014b) and present the 2010 emission figures for passenger cars. The study is aiming at being an objective reference study not guided by sectorial interests but rather built on consensus contributing parties characterised by more often than not diverging sectorial interests. Acknowledging that the JEC (2014b) is not the only relevant source, this report does not attempt to judge or compare the different sources, but uses the JEC (2014b) as its main reference, because it contains consistent and comparable figures across the board, although, the study is not aimed at a use such as the current report. Moreover, the study is continuously working with the stakeholders and academia to update to increase the validity of the results. The full range of impacts on human health, climate and the environment should be ideally considered for any given fuel, that is through Life-Cycle Assessment (LCA) studies. The JEC WTW methodology is not directly comparable with a "typical" LCA in that it considers only steps relevant to fuel production/distribution and vehicle use. Other aspects – such as the costs in terms of energy and emissions involved in building the facilities and the vehicles, or the end of life aspects are not considered. By setting system boundaries somewhat narrower than a "typical LCA, the JEC WTW methodology focusses on the major contributors to lifetime energy use and GHG emissions and allows technology and

fuel-neutral comparative estimates. Necessarily though, whenever choices are made an element of subjectivity is introduced. JEC WTW Version 4a does not provide estimates of the overall "costs to society" while at the same time it assumes that impacts are the same across Europe, which is true for emissions acting on a global scale, not entirely valid when considering energy supply, where there can be differences between Member States' energy production mix, and certainly not fit for metrics dependent on local conditions and effects such as air and water pollution. Other data sources obviously exist. Therefore the figures as far as their consideration in this report is concerned are open to discussion by the experts.

The figures are shown as CO_2 equivalents and thus include other GHGs,[12] which have been converted to CO_2 emissions. JEC (2014b), shows the calculated emission per km split on well to tank (WTT), tank to wheel (TTW) and total well to wheel (WTW). Although Chapter 4 only looks at the production of the fuels, and focus should thus also only be on WTT emissions, we have chosen to include TTW and WTW emissions to give the full picture and to ease the reading rather than having to look for the different contributions from WTT and TTW in different places in the report. The TTW emissions refer to a model passenger car, representing a typical European compact size 5-seater sedan. A number of powertrain options are assessed also considering the specific fuel. According to JEC (2014b), the WTT calculation can also be applied to other vehicle configurations, since it does not relate to the configuration of the vehicle using the fuel. We have included more details on the approach used in JEC (2014b) in Appendix A.

- **OTHER EMISSIONS.** It has not been possible to elaborate on specific sources of pollutant emissions. For the same reason, noise emissions are not included in the report. Emissions are typically tested as part of the approval procedure for new vehicles before they enter the market (sticker emissions). However, the sticker emission figures are not collected across vehicles and fuels in a consistent report. Another option to find consistent emission figures is to use the COPERT emission model.[13] COPERT does not provide general figures for specific fuels, but it can be used to calculate average vehicle related (tail pipe) emissions from individual countries with specific fleet compositions and fuel components. COPERT provides figures limited to road transport.

Hence, only few figures, based on single individual inputs, are presented for pollutants emissions

- **ENERGY CONSUMPTION.** This consists of several elements in the chain from production to final use in specific transport means. The total energy consumption depends on the energy efficiency. Energy losses occur in different parts of the conversion from input of primary energy to energy used by the vehicle while it is moving. In the report, we present this as a total energy consumption (expressed in MJ) measured per km. The figures used come from JEC (2014b). In the appendix, we provide a summary of the approach used in the calculations by JEC (2014b). Figures are reported for both the WTT and the TTW as well as for the WTW total energy consumption. Moreover, we present the WTW energy use related to renewable energy sources to give an indication of the extent of this within each fuel production pathway. JEC (2014b) provides figures for the different intermediate steps, but these are not reported here. Not all factors are however, considered in a comparable manner. Energy consumption and therefore GHG emissions for transporting refined oil-derived fuels in and out of Europe are for instance not included and these might be significant even though distance of origin are important

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[12] E.g. Nitrous Oxide N2O and Methane as described in JEC (2014a) appendix 1.
[13] http://www.emisia.com/copert/Methodology.html

factors considered for CNG and LNG. Also the growing fraction of unconventional oil in imported fuels is not quantified and might therefore underestimate the GHG intensity of these fuels.

- **MATURITY OF FUEL PRODUCTION**. This element considers at which point in the innovation cycle a fuel technology is. This spans from early R&D to full market maturity. A time horizon for the specific fuels from its readiness to enter the market and to full market penetration is part of the assessment. Readiness of combustion engines and after treatment technologies for alternative fuels. These technologies have to be closely linked to different fuel types and as such contribute significantly to the efficiency and emission issues.
- **COSTS**. The costs of production, distribution and other cost aspects of the fuel will be assessed. Generally, costs are assessed without taxes and excise duties although this may have an important impact on user prices. It is difficult to obtain information about production costs. Moreover, it is difficult to find figures, which are consistent across different fuels and thus can be allowed to be compared. JEC (2014b) for example states that "*…cost estimation for future vehicles and fuels is an uncertain process…* " and cost estimates have not been included in JEC WTW Version 4a. However, broader information on costs would exist for mature technologies, including natural gas vehicles. Figures mainly do not include taxes or other duties, but attempt to reflect the production costs only.

3.2 Elements for fuels' transport infrastructure and transport markets

The elements covered for each of the fuels in Chapter 5 with respect to refuelling/re-charging infrastructure and vehicles/vessels are:

- **MATURITY OF VEHICLE/VESSELS AND INFRASTRUCTURE TECHNOLOGY**. An overview of the market status of the technological development of vehicles/vessels and the recent infrastructure development is presented. For some fuels, focus is more on the fuel production (e.g. biofuels), which is thus covered in Chapter 4, and for other fuels more focus is on the vehicles and/or infrastructure (e.g. electric vehicles).
- **MARKET SIZE.** The current number of vehicles/vessels using the different fuels in the Member States are presented. These are compiled from different sources supplied by the EGFTF member organisations. Data on waterborne vessels and infrastructure is partly dealt with in the maturity sections and in the market perspectives sections. Figures per country are generally not presented in the report.
- **SUPPLY INFRASTRUCTURE**. In order to get a fuel from production to end consumer, infrastructure is needed. A status of the extension and diversification of the infrastructure for the different fuels is given.
- **COSTS OF INFRASTRUCTURE AND VEHICLES/VESSELS**. The costs of refuelling infrastructure and the vehicle productions cost aspects are described. Given the specific global characteristics of vessel construction, European fleet developments are not included in this report.
- **MARKET ASPECTS**. What market areas can be expected to develop in relation to the different fuels? Are there specific aspects for different fuels and how may the markets develop in the 2020, 2030 and 2050 perspectives?

4 Analysis of the Different Fuels

4.1 Electricity

4.1.1 Definition and overall description

Electricity is an energy carrier that can be converted domestically from a wide variety of primary energy sources. A certain quantity of electricity can be produced from renewable energy sources, offering a nearly well-to-wheel zero-emission pathway, although this is not always the case; e.g. when a combination of renewable and non-renewable sources are used. Electricity will continue to become increasingly low-carbon as the power sector continues to reduce in carbon intensity.

The European electricity industry has made a strong commitment to achieving carbon neutral electricity by 2050. In 2013, more than half of the total electricity generated in Europe came from low-carbon facilities. Renewables generation continued to increase, nuclear production remained stable and fossil fuel fired generation fell sharply.

In addition, the European power sector's carbon emissions are capped under the EU Emissions Trading Scheme (EU ETS), which thus also covers the electricity used to charge electric vehicles and the associated GHG emissions. Introducing EVs would thus fall under the EU ETS cap, which means that the total GHG emissions of power stations will not increase, even when more electricity is delivered for electric cars.

At present, electricity for transportation purposes is mainly used in the rail sector (76% of the final energy use in transport) where 54% of the European railway lines are electrified[14]. There is a growing trend also in road transport (see Section 5.1) and for other modes, such as air and maritime, electricity can already be used for auxiliary services in airports and ports (e.g. cold ironing), with positive impacts on local air pollution. It should be noted that the production of pollutants may be in other areas than those of usage (for example, EV in towns and power stations in the countryside), which therefore can lead to local pollution near these production sites. Electrification of public transport urban buses is also expanding rapidly as cities value them for their reduced local air pollution and noise levels. The full battery electrification of heavy-duty vehicles and long haul bus and coach fleets is not likely to happen in the short term, but such fleets may be partially electrified by the use of plug-in hybrid technology and should be considered in a long-term strategy.

The development of the electromobility, understood as all forms of electric individual and collective transport use, in the EU could provide significant advantages in terms of security of energy supply (extending the domestic market for renewables), reduction of greenhouse gas emissions, local air pollution, and dependence on imported oil increases in energy efficiency. The outcome of course, is dependent on the actual production pathways.

4.1.2 Availability and potential (2020-2030-2050)

Electricity is becoming increasingly low carbon. The share of carbon free gross electricity generation (i.e. nuclear and renewable energy forms) went up from 46% in 2000 to 52% in 2012. The European Commission (2013) has assessed that under current trends and adopted policies, this share would reach about 58% by 2020, 66% by 2030 and 73% by 2050. Eurelectric has stated that already in 2030, 80% of

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[14] European Commission (2014), EU transport in figures – Statistical Pocketbook 2014, available at: http://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2014_en.htm

European electricity will be carbon free (from renewable and nuclear electricity generation combined).

The European electricity generation mix is already changing significantly: it now includes an increased share of decentralised and variable renewable energy sources. Overall, more than 70% of the capacity installed in 2013 came from renewables (mostly wind and solar)15. In 2013, about 27% of the electricity produced came from renewable energy sources in the EU28. Significant energy storage or demand-side measures will be needed to accommodate growing shares of renewable energy sources that, due to their variability, could present challenges to balancing supply and demand on the grid. Electric vehicles could bring a solution here as part of a smart grid environment. Acting as decentralized electric storage, the charging of electric vehicles can be regulated to coincide with the availability of renewable electricity generation, leading to more efficient utilisation of generation capacity avoiding costly add-on capacities. In the longer term with a sufficient high number of vehicles, the batteries of vehicles have the potential to be used to supply electricity back to the grid during periods of low renewable electricity generation but "peak" demand. The control mechanism for load management can be enabled by the grid, by the charging point, or by the vehicle itself, while a communication system with the grid allows the charging process to take actual grid capabilities into account (intelligent algorithms can be distributed at all three levels) as well as customers preferences. The ability of electric vehicles to be used in a smart, controlled way could therefore help minimise or eventually avoid distribution grid reinforcements while facilitating the integration of renewables and meeting customers' mobility needs.

4.1.3 **Emissions**

Electric vehicles not only have zero-tailpipe emissions, but they can also make a significant contribution to removing GHG emissions from transport even when emissions from the power stations are taken into consideration. With the average carbon intensity of the power sector, electric vehicles emit less GHG than their internal combustion equivalents.

Supplying renewables and other low-carbon power to EVs clearly enforces their environmental advantage.

The indirectly (calculated) "tail pipe emissions" of BEVs need to be put into a timeline perspective also. A BEV car sold today will have declining calculated tail pipe emission during its lifetime – which is totally depending on the change in electricity production in the given region or country relying on the decarbonisation pace of the power sector. Based on the estimated carbon intensity of the power sector according to the EU reference scenario, by 2035 the average electric vehicle could deliver emissions of about 28 g CO2/km16. Given the European electricity sector's commitment for decarbonisation by 2050, coupled with an increasing deployment of RES, electric vehicles have a potential to become nearly zero-carbon in terms of GHG emissions by that time.

According to JEC (2014b), the 2010 EU28 power generation mix gives GHG WTT emissions of 78 g CO_2/km for BEV.17 The WTW emissions for BEVs are the same as the WTT emissions. The GHG emissions for PHEV are 36 g CO_2/km related to the

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[15] EURELECTRIC Power Statistics 2015 "A sector in transformation: Electricity industry trends and figures"
[16] Estimated power sector carbon intensity of around 140 g CO2/kWh in 2035, European Commission Trends to 2050
[17] The WTW figures are calculated using a WTT emission for low voltage distribution in the JEC calculations are 540 gCO2eq/kWh (JEC, 2014a)

power used. When TTW emissions are included, the total WTW GHG emissions are 111 g CO_2/km for PHEV (gasoline hybrid), and 105 g CO_2/km for PHEV (diesel hybrids). The WTT and TTW figures are shown together with the WTW figures in Table 4-1.

Table 4-1: WTT, WTW and TTW GHG emissions (CO_2 equivalents) from BEV and PHEV vehicles based on the EU28 electricity production mix in 2010. Source JEC (2014b) Appendix 1.

	WTT*	TTW	WTW
		g CO_2/km	
BEV	78	0	78
PHEV (Gasoline)	36	75	111
PHEV (Diesel)	36	68	105
Conventional gasoline	29	156	185
Conventional diesel	25	120	145

** Sum of emissions from fuel and from electricity*

The emissions will vary considerably depending on the way electricity is produced. This is illustrated in JEC (2014b) for a number of different production paths. A comparison of WTT emissions for different, selected production paths is shown in Figure 4-1 for BEV.

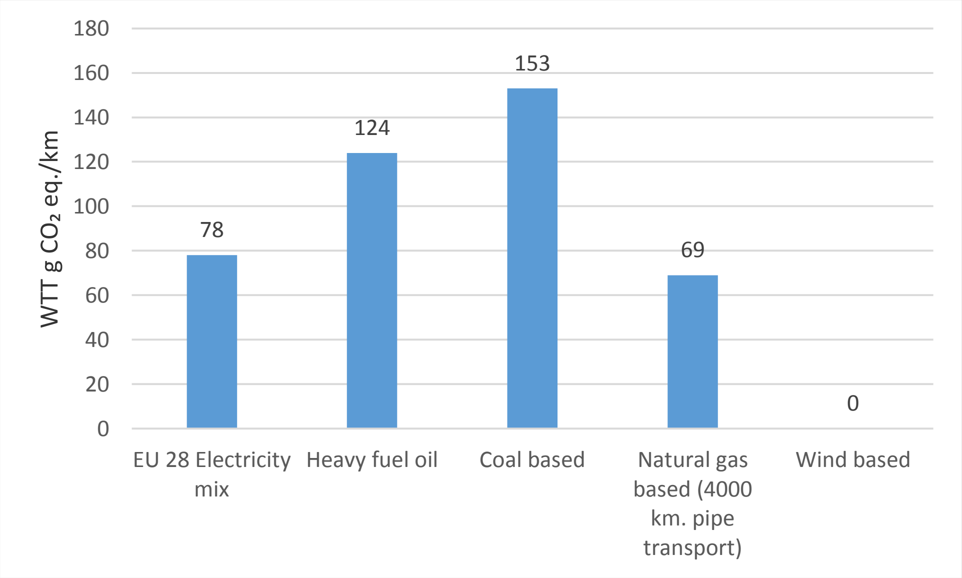

Figure 4-1: Well-to-tank (WTT) GHG emissions using selected electricity pathways for 2010 Source: JEC (2014b)[18].

IEA EU mix 2010 data for OECD Europe is 331 g CO2/kWh (61% of JRC value). Calculating the weighted average taking into account actual electric vehicle and CO2/kWh emissions per country, the result is 224 g CO2/kWh (most full electric vehicles are in Norway and France, where large shares of electricity is produced from nuclear sources and hydropower, which therefore reduce the vehicle weighted average). This is 40% of the JRC value.19 The country specific emissions depend on

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[18] Three distinct pathways for the production of CNG are currently considered in the study, According to latest statistics, 55% of the gas is sourced from within EU boarders (34 indigenous production + 21% Norway) giving total WT emissions of 69,3 g CO2 eq./km. (Source: EUROGAS statistical report 2014).

[19] The figure will thus change as vehicle fleets composition on electric and other fuels are changing.

the specific electricity production mix in these countries. Here we only present the European averages as shown in JEC (2014b), but it should be noted that these figures can be debated as also indicated here.

Electric vehicles can contribute to air quality improvement, especially in urban areas since they produce neither NOx emissions nor particles (PM) while running in electric drive mode. PM affect more people than any other pollutants. Short-term effects of particulate air pollution impair especially the respiratory tract, weaken the heart and circulatory system and lead to increased mortality rates. The Directive 2008/50/EC on ambient air quality and cleaner air for Europe, which defines, among other things, emission limit values for NO_2 and PM_{10} contributes to the EU objective on clean air.

4.1.4 Energy efficiency

Well-to-wheel energy efficiency analysis also shows that electric vehicles are more efficient than ICEs20 over a broader range of primary energy sources.21 The energy consumption for PHEVs and BEVs are shown in Table 4-2. The figures for the TTW energy consumption includes the energy consumed from the fuel (diesel and electricity) and energy from electricity. The table moreover shows the share of non-fossil (renewable) fuels consumed.

Table 4-2: Energy consumption for BEV and PHEV vehicles using the current EU28 2010 Energy mix compared with conventional vehicles. Source JEC (2014b)

	WTT MJ / 100 km	**TTW MJ / 100 km**	**WTW MJ / 100 km**	**WTW from non-fossil fuels MJ / 100 km**
BEV	118	52	170	132
PHEV (Gasoline)	52	116	168	38
PHEV (Diesel)	52	107	159	38
Conventional gasoline	39	211	250	0
Conventional diesel	33	163	196	0

4.1.5 Maturity of the technology

Electric transportation is now rather developed with several vehicle producers Introducing BEVs and PHEVs on the market.22 The battery technology is also continuously being improved, but there is still room for increasing the performance and cost of batteries (see also Section 5.1).

Electricity production is becoming increasingly low-carbon, with a growing increase in renewable energy sources, including wind power, solar power (thermal, photovoltaic and concentrated), hydroelectric power, tidal power, geothermal energy, biomass, biogas, and the renewable part of waste. According to the European Commission (2013), under current trends and adopted policies, the share of electricity generation

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[20] Internal combustion engines
[21] See JEC (2014b) WTW Version 4a
[22] The aspects related to the vehicle technology are covered in Section **Error! Reference source not ound.**.

from renewable energy sources (RES-E indicator23) would go up from 20% in 2010 to about 35% by 2020, 43% by 2030 and 50% by 2050.

4.1.6 Production costs

The developments in the EU28 power sector have significant impacts on energy costs and electricity prices, in particular in the short term. The power sector is replacing much of its production capacity over the coming years leading to increasing investments. Moreover, costs of fuel inputs are also expected to increase significantly in 2020 compared with 2010. Member States are also investing in their grid to obtain higher supply security. These investments are fully consistent with the provisions of the ENTSO-E TYNDP24 as well as the achievement of the RES25 2020 target. Smaller components of the cost increase are national taxes and ETS allowance expenditures. Hence, the average electricity price over the period 2010-20 is expected to increase by 31% as shown in Table 4-3.

Table 4-3: Evolution of cost components of electricity price in 2010-20. Source: EU Reference scenario 2013

€/MWh	Diff. 2010-2020	% contribution
Fixed and capital costs	14.2	34.5
Variable and fuel costs	4.5	11.1
Tax on fuels and ETS payments	3.8	9.1
Transmission, distribution and sales costs	7.5	18.3
Other costs (imports, recovery for RES)	8.4	20.6
Excise and VAT taxes	2.6	6.4
Average price of electricity for final demand sectors (after tax)	41.0	

The composition on the different elements comprising the electricity price is shown in Figure 4-226. The figures are shown as averages across Europe. There are obviously national differences in e.g. taxes and VAT. The main components are annual financial rents and the fuel costs, but tax, VAT and the fixed costs also are main elements. The downwards trend estimated in the E3M et al (2013) report is due to cost savings from the large restructure investments in the electricity supply, a deceleration in the increase in the gas price, and lower technology costs.

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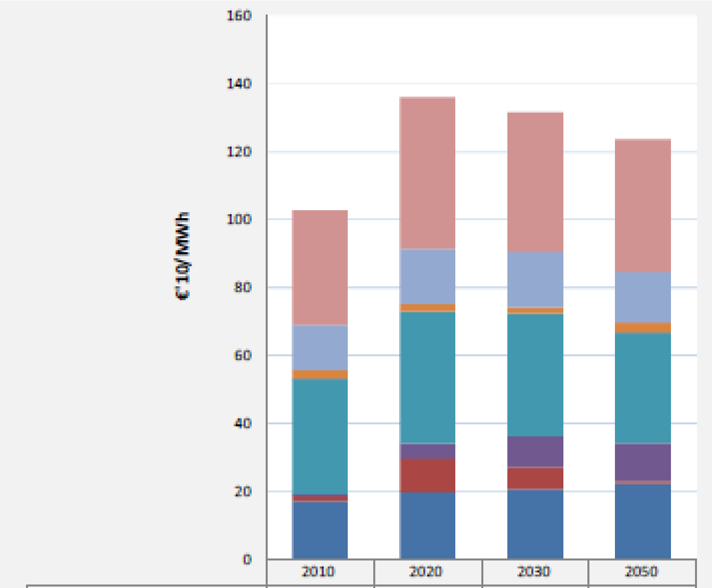
[23] Calculated according to the definitions of the Renewable Energy Directive (Directive 2009/28/EC).

[24] European Network of Transmission System Operators for Electricity (ENTSO-E); Ten Year Network Development Plan (TYNDP).

[25] Renewable Energy Sources

[26] European Commission (2013), EU energy, transport and GHG emissions – Trends to 2050: Reference scenario 2013, available at: http://ec.europa.eu/transport/media/publications/doc/trends-to-2050-update-2013.pdf



	2010	2020	2030	2050
🟥 Annual capital cost	34	45	41	39
🟦 Fixed costs	13	16	16	15
🟧 Variable costs	3	2	2	3
🟦 Fuel costs	34	39	36	33
🟪 Tax on fuels and ETS payments	1	4	9	11
🟥 Other costs (imports, recovery for RES)	2	10	6	1
🟦 Excise tax and VAT on electricity	17	20	21	22
Average price of electricity (after tax)	131	172	172	169

Figure 4-2: Cost components of average electricity price. Source: I3M-Lab et al (2013)

4.2 Hydrogen

4.2.1 Definition and overall description

FCEVs[27] and hydrogen provide an alternative proposition in the transport sector.

Similar to electricity, hydrogen is an energy carrier that can be produced from a wide variety of primary energy sources. Currently, hydrogen is predominantly produced by steam reforming of methane, via a chemical transformation process generally involving decarbonisation of a hydrocarbon. Hydrogen can also be produced from renewable or nuclear energy using electrolysis or biomethane reforming, via organic feedstock and splitting of water (here we will refer to "thermal" hydrogen), which offers zero or close-to zero-emission pathways from well to wheel.

The technology for hydrogen production is mature and cheap production pathways are in place. It still needs significant efforts to set up the necessary hydrogen refuelling station infrastructure. However, it does not require a change in user habits in terms of mobility and refuelling, and it offers substantial benefits in terms of environmental and energy sustainability.

The increase of intermittent renewable energy sources, such as solar and wind energy, in Europe's power systems is causing operational challenges, such as grid stability, and has led to calls for a greater use of energy storage amongst other measures. Hydrogen is viewed as one of the key solutions for large scale and long-term energy

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[27] Fuel Cell Electric Vehicles

storage. In order to fulfil this promise several technologies need to be further developed. For example by conversion of electricity to hydrogen, which is already possible via electrolysis.

Large scale storage of hydrogen is feasible and has been commercially proven in at least one case where hydrogen is stored in an underground salt formation. However, integration with intermittent production of hydrogen has not yet been demonstrated, whilst a suitable business case whereby the location of the storage is dictated by wind/sun patterns and geological conditions has yet to be defined. To exploit the large scale storage capacity of the Natural Gas (NG) grid, the first demonstrations of blending hydrogen into the natural gas grid are starting right now. These are still small scale and inject at a relatively low-pressure entry point.

4.2.2 Availability and potential (2020-2030-2050)

The potential for hydrogen as a fuel is significant. Hydrogen can be produced from a variety of primary energy sources. The absolute dominating pathway for production of hydrogen is steam reforming of hydrocarbons, first of all methane. Small amounts are produced through electrolysis of water. Hydrogen is produced in large quantities for industrial applications. The cost of production and energy efficiency can still be improved. In addition, significant investments would be needed in the distribution network for hydrogen, which has been identified as one of the key bottleneck towards adoption of hydrogen as large scale transportation fuel. The availability of hydrocarbon as such is not seen as a barrier against expansion of hydrogen as a future transport fuel.

4.2.3 Emissions

GHG emissions depend on the production pathway followed for the production of the hydrogen. As stated above, hydrogen is currently predominantly produced by steam reforming of methane. In this process, around 10 kg of CO_2 per kg of H2 is produced (WTT), which corresponds to 62 g CO_2 eq. per km.28 However, when used in fuel cell electric vehicles, only electricity, water and heat are produced. Thus, the CO_2 emissions at the tail pipe (TTW) are zero and WTW emissions are equal to WTT emissions.

Some of the variations in GHG emissions depending on the thermal production pathway are shown in Table 4-4. The EU mix refers both to the average extraction of natural gas and the transport of the gas until the gas is used in the vehicle (WTT).

Table 4-4: GHG emissions (CO_2 equivalents) for different thermal production pathways for compressed hydrogen. Source: JEC (2014b).

Thermal gasification path	**WTT (g CO_2 eq. /km)**
Natural gas, EU mix	62
Coal gasification, EU-mix	128
Wood gasification	9

In Table 4-5 similar figures are shown for the electrolysis pathway, where electricity is used in the hydrogen production process. Hence, the emission figures (both for thermal and electrolysis) depend on how the energy used for this process is produced.

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[28] Using the EU-mix and calculated for 2020 in JEC (2014b). Only 2020 projections are shown in the report.

Table 4-5: GHG emissions (CO_2 equivalents) for different electrolysis production pathways for compressed hydrogen. Source: JEC (2014b).

Electrolysis path	WTT (g CO_2 eq. /km)
Electricity EU mix	125
Coal gasification, EU-mix	68
Wood gasification	12
Wind	7

4.2.4 Energy efficiency

In Figure 4-3 (thermal) and Figure 4-4 (electrolysis) the energy consumption is shown for different hydrogen production paths. The 2020 projected thermal hydrogen production from natural gas gives a WTW energy consumption of 107 MJ/100 km for hydrogen fuelled passenger cars according to JEC (2014b); the WTT and TTW figures are 53 and 54 MJ/100 km respectively. The corresponding 2020 WTW projections for conventional gasoline and diesel vehicles are 175 and 150 MJ/100 km respectively. Hence, FCEVs are significantly more energy efficient than conventional vehicles.

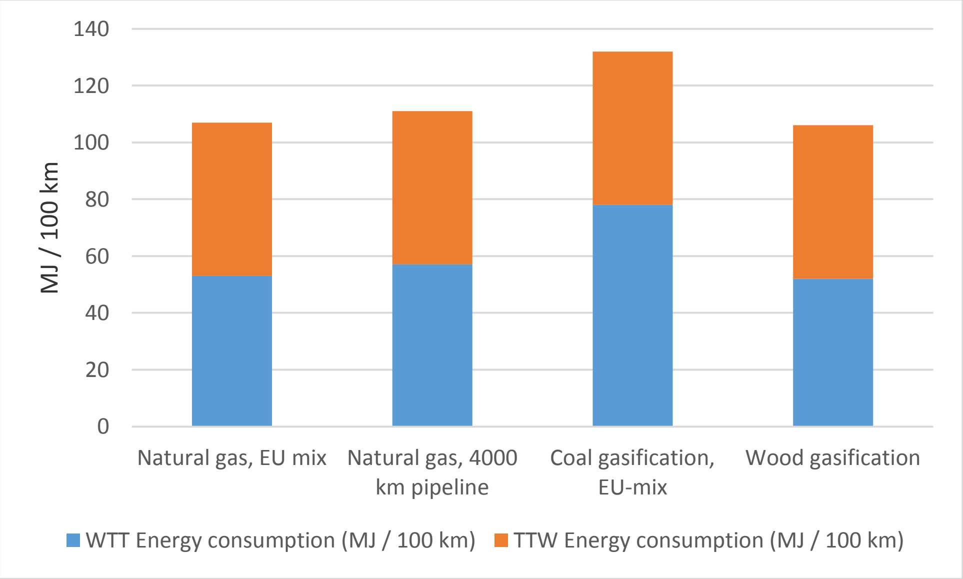

Figure 4-3: WTT and TTW energy consumption from different thermal hydrogen production pathways; 2020+ estimates. Source: JEC (2014b)[29]

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[29] JEC (2014b) does not provide energy consumption figures for natural gas in EU-mix. Hence, we have shown the 4000 km pipeline transport alternative.

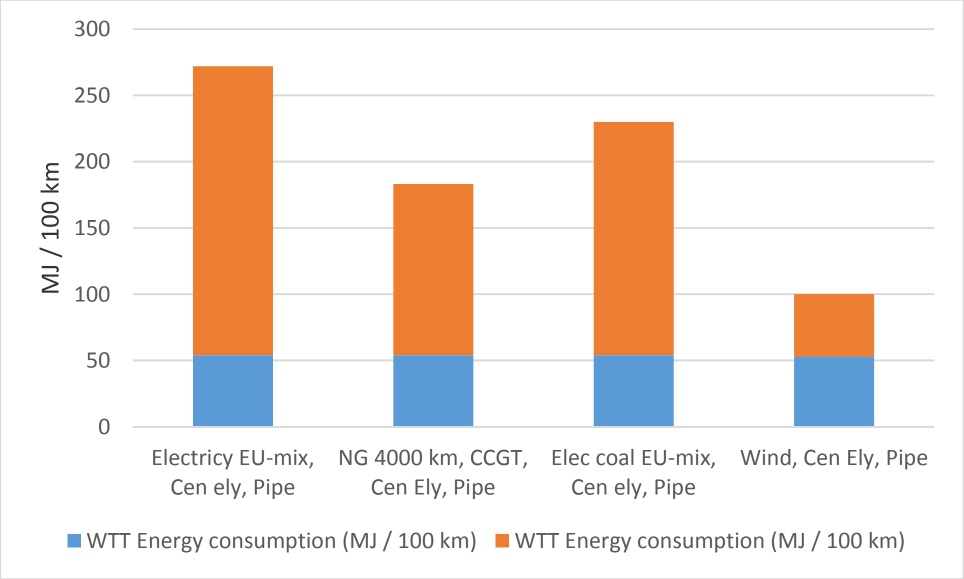

Figure 4-4: WTT and TTW energy consumption from different hydrogen electrolysis production pathways; 2020+ estimates. Source: JEC (2014b)

4.2.5 Maturity of technology

Europe is still considered a technology leader in certain FCH application-areas but other regions (e.g. Japan and the US) are developing quickly as a result of public intervention and support. Impressive technological progress has been made by European companies, especially in the transport sector, also due to good support from projects developed jointly under the European R&D framework programme. The public and private sectors came together to form the first Fuel Cell and Hydrogen Joint Undertaking (FCH JU) in 2008 to promote coordination and collaboration across Europe’s FCH sector and accelerate the commercialisation of FCH technologies. This initiative has been extended under Horizon 2020 as FCH 2 JU.

One of the perceived merits of hydrogen is again that in principle it can be produced from virtually any primary energy source. Production pathways differ in terms of cost, environmental performance, efficiency and technological maturity. Steam reforming of natural gas is the most common method of hydrogen production today.

Hydrogen is already produced in significant quantities today mostly for industrial and refinery purposes. Oil refineries, in particular, are large hydrogen consumers for hydrodesulphurisation of various streams such as gasoil and heavy oil conversion processes. However, for the use of hydrogen in fuel cells the hydrogen has to be purified to a high level, involving removal of impurities that could impact fuel cell performance. Hydrogen is stored in tanks under very high pressure (up to 700 bars).

While hydrogen has very high energy content per kilogram, it is very light in weight (a low molecular weight), even when highly compressed or liquefied. It therefore does not have high energy content per litre of space required to store it.

Direct solar energy can also be used to produce hydrogen either by thermal splitting of water or electrolysis through photovoltaic electricity. Also wind, can be used to generate the power needed to produce hydrogen. The development of the thermal splitting process is in its infancy while photovoltaic electricity is not expected to be viable at very large scale within a near horizon.30

The Power to Gas concept has the possibility to convert hydrogen into synthetic methane (CH4), via the reaction of the H2 produced with CO_2, either as a waste product from biogas plants or from the atmosphere. This Synthetic Natural Gas (SNG) has the same chemical composition as natural gas and biomethane.[31].

Additionally, hydrogen can be blended with Natural Gas, up to 5% H2 can be allowed in the gas grid and 2% in CNG as vehicle fuel.

4.2.6 Production cost of fuels

In the near to medium term fossil fuels (primarily natural gas) are likely to continue to be the least expensive feedstocks for hydrogen production. Given that their conversion still emits carbon into the atmosphere, transition to zero-emission mobility will require moving to cleaner production pathways, which have the potential to virtually eliminate LCA GHG emissions.

For example, production of hydrogen from renewable biomass is a promising mid-term option with very low net carbon emissions. In the longer term, transition to hydrogen from wind energy should enable zero-carbon mobility. While this technology is rapidly improving, high cost of electrolysers and renewable electricity constitute key barriers towards wider uptake. However, on the basis of significant benefits to coupling hydrogen production with flexible storage of off-peak renewable electricity whereas the share of RES in European electricity grids will continue to increase, these barriers have a good chance to be overcome in a not too distant future.

Different hydrogen production methods show a wide range of costs between EUR 1.9 and 10.3/kg H2.[32] [33]

4.3 Liquid Biofuels

This section deals with liquid biofuels with the following exception: Biomass to liquid (BTL) and hydro treated vegetable oils (HVO), which are treated in Section 4.5 (Synthetic and paraffinic fuels) due to the fact that biomass is one of the pathways to produce synthetic diesel. Biomethane is a gaseous biofuel, but it is treated in Section 4.4 (Natural gas) as it is to be used in natural gas vehicles.

4.3.1 Definition

Although there are different definitions for biofuels, this report uses the following definitions:

> *"Biofuels' means liquid or gaseous fuel for transport produced from biomass" from Directive 2009/28/EC, point (i) of Article 2*

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[30] JEC (2014b)

[31] See also Section 4.5 for other synthetic approaches.

[32] Corresponding to approximately 1.5 to 8.5 Eurocents per MJ. with an energy density of 120 MJ/kg H2. Cost figures based on FCH JU (2012) Urban buses: alternative powertrains for Europe. http://www.fch-ju.eu/sites/default/files/20121029%20Urban%20buses%2C%20alternative%20powertrains%20for%20Europe%20-%20Final%20report.pdf

[33] As a rule of thumb the kg/100 km figures can be compared to gallons/100 km

"Biofuels can be produced from a wide range of feedstock through technologies in constant evolution and used directly or blended with conventional fossil fuels. They include bioethanol, bio-methanol[34] *and higher bioalcohols, biodiesel (fatty-acid methyl ester, FAME), pure vegetable oils, hydrotreated vegetable oils, dimethyl ether (DME), and organic compounds."* from "Clean Power for Transport: A European alternative fuels strategy", Article 2.4 named Biofuels (liquid), COM(2013) 17 final.

Moreover, the biofuels can be classified in various ways. The chosen classification for this reports is:

FIRST GENERATION LIQUID BIOFUELS refer to ethanol from e.g. sugar or starch rich crops, biodiesel (FAME) from vegetable oils, and pure vegetable oil. The production of these fuels is based on traditional chemistry such as fermentation and esterification and other well-established processes that in essence are quite mature.

SECOND GENERATION LIQUID BIOFUELS encompass a broad range of biofuels produced from feedstock that is not used as food or feed, e.g. lignocellulosic materials (like short rotation forestry or coppice), the organic part of municipal solid and liquid waste, forest and agricultural residues, which is for example the primary production source for biomethane used in transport. They may also include bioethanol and biodiesel produced from conventional technologies but based on novel starch or energy crops such as Jatropha. The hydro treatment of vegetable oils, animal fats or waste cooking oils has also been gaining ground as a solution to the increasing pressure to find alternatives for fossil fuels in transport. Production technologies are usually more complex and expensive than for first generation biofuels, but second generation biofuels are generally considered more sustainable, with the potential for greater GHG emission savings compared to first generation biofuels – naturally depending on the production pathways[35].

THIRD GENERATION LIQUID BIOFUELS generally include biofuel production routes, which are at the earlier stages of research and development or are significantly far from commercialization (e.g. biofuels from algae, hydrogen from biomass, etc.) or synthetic methane where first pilots exist.

Second and third generation biofuels produced from non-food feedstock (e.g. wastes, agricultural & forestry residues, energy crops, algae) are also referred to as advanced biofuels as long as the raw materials are processed in the right manner.

4.3.2 Overall description

Liquid and gaseous biofuels are expected to contribute significantly to the achievement by 2020 of the targets set in the Renewable Energy Directive (RED)[36] and the Fuel Quality Directive (FQD)[37]. Liquid biofuels are currently the most important type of alternative fuels, accounting for about 5% of the total fuels consumed by road transport ***in the European Union. A large part of this is through so-called drop-in fuels, where biofuels are blended with conventional fuels (ethanol in gasoline and biodiesel blended with diesel).***

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[34] Biomethane is thus also a biofuel, but is considered in the next subsection together with natural gas.

[35] Dedicated energy crops like miscanthus, switchgrass etc. could also be grown on marginal/degraded land. However, this may often require intensive use of water/fertilisers. Sometimes also energy crops are grown on agricultural land thus competing with food/feed crops and possibly causing indirect land use change (ILUC).

[36] Directive 2009/28/EC, sets a binding target of 20% share of renewable energy in the EU and a 10% share for renewable energy in the transport sector.

[37] Directive 98/70/EC sets target by 2020 for a 6% reduction in the GHG intensity of fuels used in road transport and non-road mobile machinery

ILUCIndirect Land Use Change (ILUC) relates to the release of carbon emissions due to the use of existing cropland for biofuel production and the resulting displacement of food (or other) production to previously uncultivated land.

The Commission adopted a proposal (ILUC Directive) for amending the Fuel Quality Directive and the Renewable Energy Directive on 17 October 2012. The aim of the proposed ILUC Directive was to foster the transition to advanced (low ILUC) biofuels that bring substantial greenhouse gas (GHG) emissions savings while ensuring that estimated ILUC emissions are reported. The proposals sought to do so while protecting existing investments until 2020. In particular it aimed to:

- limit the contribution that conventional biofuels (with a risk of ILUC emissions) make towards the overall renewable energy and the transport targets in the Renewable Energy Directive (RED);
- improve the GHG performance of biofuel production processes by raising the GHG saving threshold for new installations, subject to protecting installations already in operation on 1 July 2014;
- encourage market penetration of advanced (low-ILUC) biofuels by allowing such fuels to contribute more to the targets in the RED than conventional biofuels;
- improve the reporting of GHG emissions by obliging Member States and fuel suppliers to report the estimated ILUC emissions of biofuels.

The Council adopted its Common Position at First Reading on 10 December 2014, including raising the cape to 7% for first generation biofuels. The Council encouraged the transition to advanced biofuels, by inviting Member States to promote the consumption of such biofuels and requiring them to set non-legally-binding national sub-targets for advanced biofuels based on a reference value of 0.5 percentage points of the 10 % target for renewable energy in transport.

The Environment Committee of the European Parliament adopted its 2nd reading report prepared by Finnish MEP Nils Torvalds on the compromise text on the proposed directive on 24th of February 2015. The EP position modifies the Council text on a number of key issues of the reform. It demands a cap on first generation biofuels at 6%, its application to both directives (RED and FQD) and links the cap to subsidies. It also demands the inclusion of ILUC factors in the FQD for accounting purposes post 2020 and in the RED for reporting. The binding target for 2nd generation biofuels suggested by the EP is set at 1.25%, but at the same time the EP also requested the introduction of sustainability criteria such as the respect of the principles of waste hierarchy and cascading use. The text of the agreement was approved by the plenary session of the European Parliament on 29 April in Strasbourg and then sent for final adoption by the Council. Member states will have to enact the legislation by 2017.

The main points of the agreement are:

- **FIRST-GENERATION BIOFUELS**. The compromise approved states that there will be a limit of 7% on the contribution that first-generation biofuels (from cereal and other starch rich crops, sugars and oil crops) and from other crops grown as main crops primarily for energy purposes on agricultural land can make to renewable energy targets in 2020. Current legislation requires EU member states to ensure that renewable energy accounts for at least 10% of energy consumption in transport by 2020 with no restrictions on particular types of biofuel.
- **SECOND AND THIRD GENERATION BIOFUELS.** EU member states will have to set national targets, not later than 18 months after the Directive enters into force, for advanced biofuels. The agreement sets reference value of 0.5% for the share of

energy to be produced from advanced biofuels as a percentage of the energy derived from renewable sources in all forms of transport by 2020. Member states may set a lower target on certain grounds, such as a limited potential for production, technical or climatic constraints, or the existence of national policies that already allocate commensurate funding to incentives for energy efficiency and electric transport.

- **DELETION OF MULTIPLE COUNTING TOWARDS THE OVERALL RED TARGET**. The extension of multiple counting of advanced biofuels to the overall RED target has been deleted.
- **REPORTING**. Fuel suppliers will report the estimated level of emissions caused by indirect land-use change (ILUC) to EU countries and the Commission. The Commission will then report and publish data about these ILUC-related emissions.

Biofuels can be used in all modes of transport as blend in fuels. However, the aviation sector in particular seems to have no alternatives, but sustainable biofuels and some synthetic fuels if it is going to meet industry carbon reduction targets for 2050 without severely curtailing growth.

Liquid biofuels are currently used blended with conventional fuels in different percentages or form (e.g. ethanol or ETBE in E5, and E10, or in E85 for use in flexi-fuel vehicles E85, FAME in B5 and B7). High biofuels blends or neat biofuels without any blending, are used in road dedicated fleets.[38] A summary of the use of different biofuel blends in the EU are shown in Table 4-6.

Table 4-6: EU Member States initiatives for biofuels blends and neat biofuels. Source: JEC (2014a)

Blending grade	**EU Member State**	**Brief description**
E10	France, Finland, Germany	Up to 10% v/v ethanol-equivalent blending in gasoline (Annex I of the Fuel Quality Directive) and EN228:2012
E85	Austria, Germany, France, Sweden	Up to 85% v/v ethanol blending in gasoline for so-called flexi-fuel vehicles (FFV)
B7	Mainly whole of EU B8 permitted in France since beginning 2015, but actual availability unknown	Up to 7% v/v FAME blending in diesel fuel (Annex II of the Fuel Quality Directive) and EN590:2013
	Germany	Plus 3% of renewable diesel
B20	Poland	For captive fleets of dedicated vehicles
B30	France Czech Republic	For captive fleets of dedicated vehicles
B100 / Biodiesel	Germany	For specially adapted vehicles
Advanced biofuels for aviation	International	Certified drop-in biofuels for all existing aircrafts

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[38] Another type of biofuel is biomethane, without blend limitation and fully interchangeable with natural gas. It can be immediately used in existing CNG and LNG vehicle and infrastructure technologies. Biomethane is described together with natural gas in Section 4.4.

Advanced biofuels serve niche segments of the market or pilot projects in aviation. As far as aviation is concerned, three pathways are already certified and can be used for commercial flights without any restriction: synthetic paraffins from Fischer-Tropsch process (up to 50% v/v), from hydrotreatment of oils (up to 50% v/v) and from selected biological process (Total / Amyris process, up to 10% v/v).

Biofuels can be produced from a wide range of biomass feedstock. However, most of today's biofuels are produced from agricultural crops like corn, sugar cane and rapeseed. While less than 1% of global cropland[i] are used for producing biofuels, the relative importance of biofuels within certain global markets is significant. For example, globally 16% of vegetable oils (rapeseed, soybean, palm and sunflower oil) are used for biodiesel, 15% of maize (8% at the EU level[39] and some 2% of wheat) are used for bioethanol. About 80% of the biofuels consumed in the EU are currently produced domestically[40], with the share of imports expected to grow towards 2020.[41]

The EU ambitions for 2nd generation biofuels will need to be confronted with the increasing demand of biomass for bioenergy uses in other sectors. Bioenergy consumption is expected to grow by 41% (according to the NREAPs) in the 2012 – 2020 period. This will lead to additional demand for the biomass including the feedstock currently considered for the production of advanced biofuels.

4.3.3 Availability and potential (2020-2030-2050)

The growth of biofuel consumption for use in transport in the European Union (EU-28) has dwindled in the past few years and finally dropped by about 1 Mtoe (6.8%) between 2012 and 2013, according to EurObserv'ER, to a consumption level of 13.6 Mtoe. Nevertheless, biofuel consumption, certified and thus eligible for inclusion in European targets, increased slightly by 1.1% to 11.8 Mtoe.

Until 2012 blending mandates, supply obligations and financial incentives for alternative transport fuels facilitated rapid growth of the use of liquid biofuels in the EU following the introduction of indicative targets for biofuels and other renewable energy sources in the so-called "Biofuel Directive" (2003/30/EC) and the introduction of a legally binding 2020 target of 10% share of renewable energy sources in the transport sector in the Renewable Energy Directive (2009/28/EC).

However, since the entry into force of the Renewable Energy Directive, investment in biofuels, especially advanced biofuels, has dried up. In the case of ethanol, only two new production facilities came to light.

In 2013 biofuels consumption in the EU declined due to a changing global biofuel market and due to the ongoing negotiations (ILUC Directive[42]) on the revision of the EU sustainability scheme for biofuels as mentioned above. The practice of double counting has also contributed to this decline. The entire biofuels' production and supply chain has to be focussed on sustainability for all supported biofuels (in order to count towards the EU and national renewable energy targets, obligations and financial incentives). The sustainability certification of biofuels is currently done at the national level as well as through voluntary schemes, which have been approved by the

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[39] Source: CIC International Grain Council, www.igc.int
[40] SWD(2014) 259 final, available at:
http://ec.europa.eu/energy/renewables/bioenergy/doc/2014_biomass_state_of_play_.pdf
http://www.eurobserv-er.org/downloads.asp
[41] As outlined in e.g. OECD FAO (2012) Agricultural Outlook 2012.
[42] COM(2012) 595 final

European Commission (EC). So far, the EC has recognised 19 voluntary certification schemes that apply directly in all EU28 Member States.

The development in the use of biofuels is influenced by several factors, where both the RED and the FQD play important roles in securing that it is possible to use biofuels in the transport sector and that biofuels are produced sustainably.

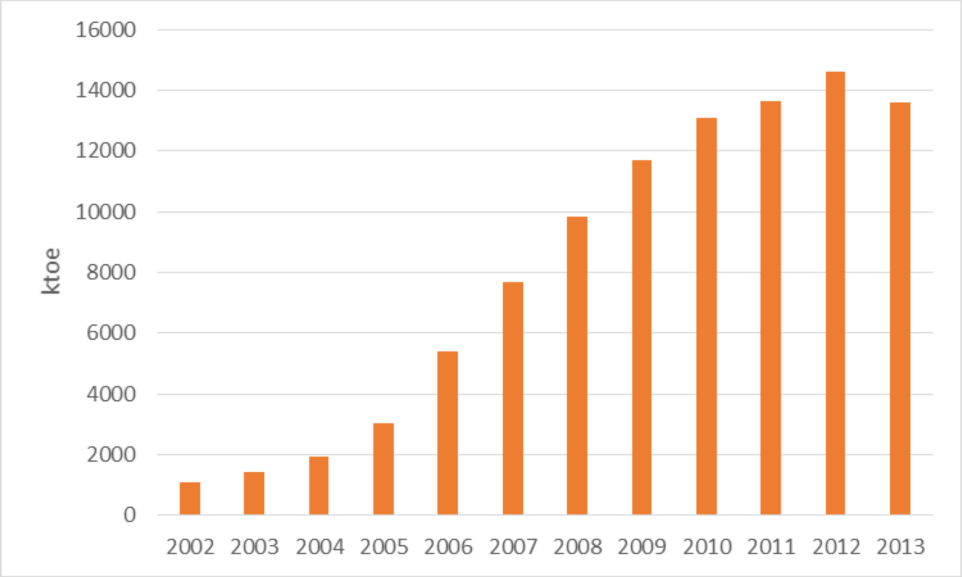

Figure 4-5: The trend in biofuel consumption for transport (ktoe) in EU28. Source: Eurobserv'er (2014). Note: 2013 figure is estimated

The share of transport biofuels consumption in the EU was 4.2% in 2012.[43] The consumption has grown steadily until 2012 as shown in Figure 4-5, but a small decline was seen in 2013. Consumption of biofuels represented a share of about 2% of the world's transport fuels in 2012, but new technologies (2nd and 3rd generation) offer a considerable potential for growth in the coming years. Under Current Policies, biofuels would represent about 3% in 2020, 3.8% in 2030 and 4.6% by 2040 (IEA, 2014). The total potential for biofuels is estimated in IEA (2014) to be 18% of the world's transport fuel by 2040 in the 2050 scenario.

An analysis presented in the Biomass Futures Atlas[44] estimates that at present there are 314 Mtoe of potential bioenergy resource in Europe and that under the reference scenario this could increase to 429 Mtoe in 2020, falling slightly to 411 Mtoe by 2030. Advanced biofuels utilizing thermo chemical processes has a conversion efficiency of 50-60% depending on product, which means that production potential is between 175 and 250 Mtoe depending on scenario and production efficiency. To substitute EU consumption of fossil fuels there is thus a potential of between 50% and 70% for biofuels. Biomass resources set aside for other needs may alter the potential considerably. According to the assessment for all periods and scenarios the largest

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[43] Comparing the 14.608 million toe with the total EU energy consumption for transport of 351.1 million reported by Eurostat.
http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Consumption_of_energy

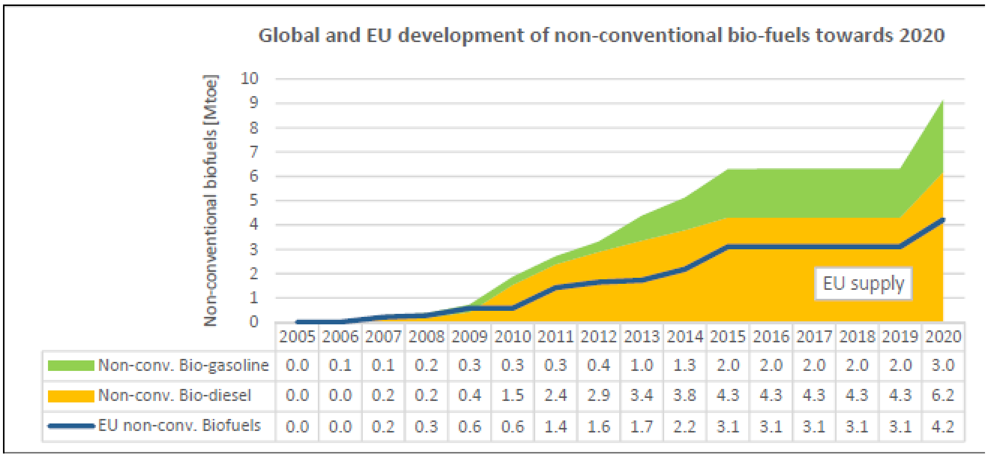
[44] Biomass Futures (2012) Atlas of EU biomass potentials. Deliverable 3.3: Spatially detailed and quantified overview of EU biomass potential taking into account the main criteria determining biomass availability from different sources.
http://www.biomassfutures.eu/public_docs/final_deliverables/WP3/D3.3%20%20Atlas%20of%20technical%20 and%20economic%20biomass%20potential.pdf

potential appears within the agricultural residues class i.e. manure, straw and cutting/pruning from permanent crops and in the forestry biomass segments. (e.g. ERTRAC Working Group: Energy and Environment, 2014).

Table 4-7: Production capacity of bio-ethanol and FAME in the EU27. 2010-2012. Source: JEC, 2014a

Bio-ethanol (EU27)	**2010**		**2012**
Production capacity installed	3.4 Mtoe		4.1 Mtoe
Actual production	1.5 Mtoe		2.2 Mtoe
Utilization	43%		54%
Production capacity under construction	0.9 Mtoe		0.2 Mtoe
Bio-diesel (EU27)		**2011**	**2012**
Production capacity installed	18.4 Mtoe in 2009	19.7 Mtoe	20.9 Mtoe
Actual production	6.9 Mtoe in 2009	7.6 Mtoe	-
Utilization (2008 and 2011)	37% in 2008	39%	-
Production capacity under construction	-	-	-

The JEC (2014a) reported the evolution of European production capacity and utilization rate if installed capacity for conventional biofuels between 2010 and 2012 as shown in Table 4-7, while the IEA (2014) has prepared projections of the demand for ethanol and biodiesel in different regions of the world as shown in Table 4-8. JEC (2014a) has also prepared a projection of non-conventional biofuels[45] until 2020, as shown in Figure 4-6.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
🟩 Non-conv. Bio-gasoline	0.0	0.1	0.1	0.2	0.3	0.3	0.3	0.4	1.0	1.3	2.0	2.0	2.0	2.0	2.0	3.0
🟨 Non-conv. Bio-diesel	0.0	0.0	0.2	0.2	0.4	1.5	2.4	2.9	3.4	3.8	4.3	4.3	4.3	4.3	4.3	6.2
— EU non-conv. Biofuels	0.0	0.0	0.2	0.3	0.6	0.6	1.4	1.6	1.7	2.2	3.1	3.1	3.1	3.1	3.1	4.2

Figure 4-6: Global and EU non-conventional biofuels outlook 2020. Source: JEC (2014a).

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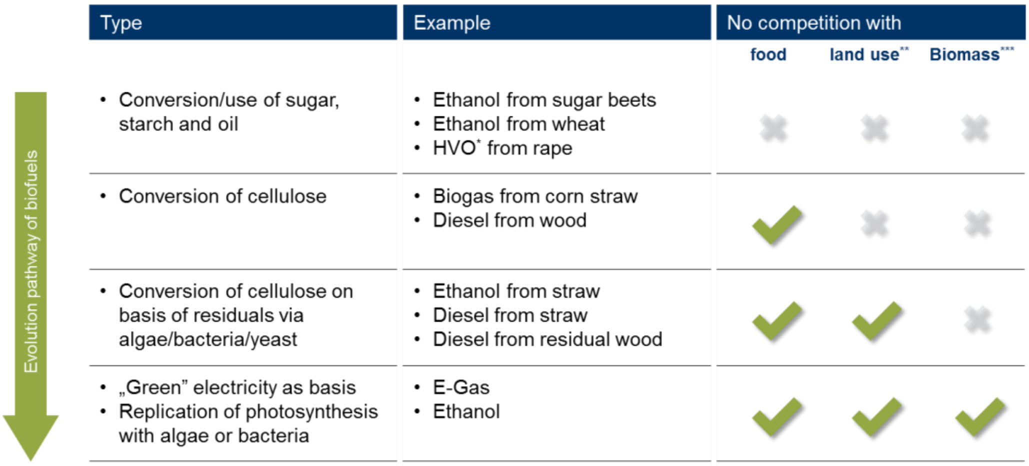
[45] According to JEC (2014a) non-conventional biofuels include e.g. HVO from vegetable oils, and FAME from waste oil

Table 4-8: Ethanol and biodiesel consumption in road transport by region in the New Policies Scenario[46] (Mboe/d). Source: IEA, 2014.

	Ethanol		Biodiesel		Total		Share of road-transport	
	2012	2040	2012	2040	2012	2040	2012	2040
OECD	0.6	1.6	0.3	0.8	0.9	2.4	4%	13%
Americas	0.5	1.4	0.0	0.3	0.6	1.7	4%	15%
United States	0.5	1.3	0.0	0.3	0.6	1.6	5%	17%
Europe	0.1	0.2	0.2	0.5	0.3	0.7	5%	14%
Non-OECD	0.2	1.7	0.1	0.4	0.4	2.1	2%	6%
E. Europe/Eurasia	0.0	0.0	0.0	0.0	0.0	0.0	0%	2%
Asia	0.0	0.8	0.0	0.1	0.1	1.0	1%	5%
China	0.0	0.5	0.0	0.0	0.0	0.5	1%	5%
India	0.0	0.3	0.0	0.0	0.0	0.3	0%	5%
Latin America	0.2	0.8	0.1	0.2	0.3	1.0	9%	22%
Brazil	0.2	0.7	0.1	0.1	0.3	0.8	17%	32%
World	0.8	3.3	0.4	1.2	1.3	4.5	3%	8%
European Union	0.1	0.2	0.2	0.5	0.3	0.7	5%	16%

Figure 4-7 illustrates the evolution pathways of biofuels for roads transport and the competition with food, land use and biomass.



Type	Example	No competition with food	No competition with land use**	No competition with Biomass***
• Conversion/use of sugar, starch and oil	• Ethanol from sugar beets • Ethanol from wheat • HVO* from rape	✗	✗	✗
• Conversion of cellulose	• Biogas from corn straw • Diesel from wood	✓	✗	✗
• Conversion of cellulose on basis of residuals via algae/bacteria/yeast	• Ethanol from straw • Diesel from straw • Diesel from residual wood	✓	✓	✗
• „Green" electricity as basis • Replication of photosynthesis with algae or bacteria	• E-Gas • Ethanol	✓	✓	✓

* HVO Hydrotreated Vegetable Oil
** agricultural land
*** biomass competition e.g. for heating

Figure 4-7: Competitive assessment of renewable energy. Source: Volkswagen AG

Based on an assessment of the availability of sustainable biomass (focusing on residues and waste only), it is estimated that biofuels based on agricultural and forestry residues and waste[47] could contribute between 12 and 15% of energy for the transport sector by 2030, representing overall GHG savings of around 8 to 11%. A

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[46] IEA (2014) World energy outlook, 2014

[47] Malins et al. (2014) "Wasted. Europe's untapped resource. An assessment of advanced biofuels from waste and residues

major share of production would need to come from advanced biofuels derived from wastes and residues, which should make up over 50% of the growth in biofuel supply between now and 2030.

In addition to significant GHG emission reductions in the transport sector, biofuels can help ensure energy security and socioeconomic development in rural areas. Rural energy security goals are completely separate from EU transport biofuel targets. Local energy security would be fostered by local consumption of biofuels. To achieve this target, strong and balanced policy efforts are required that create a stable investment environment and allow commercialization of 2nd and 3rd generation biofuel technologies[48] (IEA, 2013).

4.3.4 Emissions

JEC (2014b) has assessed the GHG emissions for biofuels produced from different bio-based feedstocks. Examples of the WTT, TTW and WTW GHG emissions for the different blend biofuels (biodiesel and ethanol) are shown in Table 4-9. JEC(2014b) contains a number of additional pathways, that could not be presented here.

According to the JEC (2014b) figures most biofuels have significant GHG emission reduction. The rate of reduction varies considerably from a 26% (from wheat for the production of 1st generation of bioethanol) to 81% (from waste for the production of 2nd generation bioethanol/biodiesel non land use), and there are specific paths with higher GHG emissions as well. The larger effects are obtained when co-products are used for energy purposes. For further details on individual pathways, we refer to the JEC (2014b) Appendix 1 as well as Section 3.4 of the main report.

Table 4-9: The range of WTT, WTW and TTW GHG emissions (CO_2 equivalents) for a selection different biofuels for 2010. Source: JEC (2014b) Appendix 1

Alternative fuel	**WTT g CO_2 /km**	**TTW g CO_2/km**	**WTW g CO_2 /km**
Biodiesel (Neat fuel equivalent)	-101 to -22	125	44 - 103
B7	14 - 19	120	137 - 140
Ethanol (Neat fuel equivalent)	-127 to 30	146	19 - 176
E10	17 - 28	150	166 - 178
E20	6 – 28	148	154 - 176
E85	-82 to 29	143	61 - 171
Conventional gasoline	29	156	185
Conventional diesel	25	120	145

JEC (2014b) has the following additional comments regarding the GHG emissions from biofuels that are also relevant to be included here:

- The fossil energy and GHG savings of conventionally produced biofuels such as ethanol and biodiesel are critically dependent on manufacturing processes and the use of co-products.
- The GHG balance is particularly uncertain because of the extreme variability of nitrous oxide emissions from agriculture.
- When upgrading a vegetable oil to a road fuel, the transesterification and hydrotreating routes are broadly equivalent in terms of GHG emissions.

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[48] IEA (2013) World Energy outlook 2013

- Current E10 and B7 market fuels deliver fossil energy savings of 3-4% and GHG savings of 2-3% respectively.

There are also other sources looking at GHG emissions from biofuels as mentioned in the introduction. We have not included a review of these sources in this report, since these sources in most cases do not cover all other fuels consistently, as does the JEC (2014b).

There is not a consolidated source for other pollutant emissions as there is for GHG emissions. According to some sources, biodiesel (FAME) blends produce slightly less particulate matter (PM), carbon monoxide and hydrocarbon emissions than conventional diesel, but can increase NO_X emissions and produce other pollutants such as aldehydes. Bioethanol blends reduce *significantly NOx emissions*.

4.3.5 Energy efficiency

JEC (2014b) has also considered the energy efficiency of the different biofuels. In Table 4-7, the range of energy consumed as WTW and TTW are shown for the groups of biofuels. The biofuel pathways typically have higher WTT, TTW and WTW energy consumption per 100 km than conventional fossil fuels. From the table, it is also clear that the specific production path may have significant importance for the actual energy efficiency. It must also be taken into account that replacing gasoline, for which a significant excess of production is present in Europe, leading to energy consumption for exporting it to the US and other markets, is less interesting than diesel replacement, for which there is a serious deficit of production, leading to energy consumption for importing it.

Table 4-7: The range of WTT, WTW and TTW energy consumptions for different biofuels for 2010. Source: JEC (2014b) Appendix 1

Alternative fuel	WTT MJ / 100 km	TTW MJ / 100/km	WTW MJ / 100/km	WTW from non-fossil fuels MJ/100 km
Biodiesel (Neat fuel equivalents)	45 - 437	163	207 - 600	154 - 509
B7	31 - 56	163	193 - 219	12 - 34
Ethanol (Neat fuel equivalent)	187 – 427	204	391 - 630	316 - 595
E10	48 - 64	204	252 - 268	24 - 40
E20	58 - 91	201	261 - 284	52 - 85
E85	142 - 312	199	341 - 459	224 - 421
Conventional gasoline	39	211	250	0
Conventional diesel	33	163	196	0

4.3.6 Maturity of technology

Biofuels are already part of the transport fuels' slate (e.g. E5, E10, E85, and B7) and the infrastructure for the supply of biofuels is in place. However, sustainability concerns, in particular regarding possible ILUC effects, are the main barrier to the first generation biofuels in getting political support.

The progress is focused on the development of advanced biofuels which are considered more sustainable as the feedstock and processes in use offer greater levels of GHG reduction and do not compete with food crops for land use.

Some examples of these developments are:

- The Crescentino (Italy) plant, which is the world's first commercial cellulosic ethanol plant in the world, produces 75 million litres of cellulosic ethanol per year from agricultural waste.
- The demonstration plant in Babilafuente (Salamanca, Spain) which uses W2B[49] technology developed by Abengoa to produce second generation biofuels from municipal solid wastes (MSW) using a fermentation treatment and enzymatic hydrolysis. The plant has a capacity to treat 25,000 tons of MSW, from which up to 1.5 million litres of bioethanol are produced for use as fuel.
- In Germany, Clariant started operation of Germany´s largest demonstration plant with an annual capacity of up to 1,000 tons of ethanol in July 2012. Its key technology is based on feedstock specific biocatalysts, which efficiently provide access to the sugars contented in the straw, an integrated enzyme production, simultaneous C5 and C6 fermentation and an energy-saving ethanol separation method. Since January 2014 Clariant together with Haltermann and Mercedes-Benz run a fleet test of cellulosic E20 (Sunliquid® 20 fuel containing 20% ethanol coming from straw). Initial results are very promising and demonstrate a 50% improvement in particulate emissions while maintaining the same consumption.
- In October 2014, Beta Renewables and BioChemtex announced an agreement with Energochemica SE for the construction of a 55,000 metric ton commercial facility in Strazske, Slovak Republic, to produce cellulosic ethanol from non-food biomass.
- In Finland, in December 2014, the Ministry of Employment and Economy granted €30m to Suomen Bioetanoli Oy to support development of a 90 MMly commercial cellulosic ethanol plant at Myllykoski
- In Denmark, in June 2014, DONG announced a new project which involves commercial-scale production of second generation ethanol from plant dry matter in Holstebro. The plant will produce 64.4 Ml of ethanol.
- Solena Fuels in partnership with British Airways has committed to building the world's first facility to convert landfill waste into jet fuel. It is expected that approximately 575,000 tonnes of post-recycled waste normally destined for landfill or incineration will instead be converted into 120,000 tonnes of clean burning liquid fuels using Solena's innovative integrated technology. British Airways has made a long-term commitment to purchase all 50,000 tonnes per annum of the jet fuel produced at market competitive rates.[50] In relation to this another interesting application was the conversion of cruise vessel passenger waste into biomass at port.

Moreover, a significant[51] number of demonstration and pilot plants to produce advance biofuels from biochemical and thermochemical technologies (including BTL processes) are running or planned in Europe. Among thermochemical and BTL processes, the addition of clean Hydrogen (e.g. Hydrogen produced from low carbon sources) at different steps of the process (combustion, Fischer Tropsch) in the process could increase dramatically the quantity of biofuels produced for a given quantity of

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[49] Waste to Biofuel

[50] http://www.solenafuels.com/index.php/greensky-london

[51] Status of 2nd Generation Biofuels Demonstration Facilities in June 2 010A REPORT TO IEA BIOENERGY TASK 39

biomass. A large demonstration project is carried out in France, leaded by CEA to check technical and economically feasibility.

Engine technology: Current engine technologies can only accommodate a relatively low biofuel content. Alternative fuels quite frequently feature other heating values, lubrication and corrosion properties. In case of compression ignition engines, the fuel can have a significant impact on the performance of the exhaust gas after-treatment systems such as DPF and SCR. Spark ignition engines are affected by the knock stability and volatility of particular fuels. Consequently, the introduction of alternative fuels will require specific engine developments including adopted engine control strategies based on new real or virtual sensors.

4.3.7 Production cost of fuels

The production of biofuels involves economic activity and employment all along the supply chain; in agriculture, logistics and at biofuels production facilities, but also in sectors that supply to or support biofuels supply chains, and is generally more labour intensive than fossil fuels. The production of advanced biofuels from waste materials for all transport modes could generate EUR 15 billion revenues to the rural economy and up to 300,000 new jobs by 2030 (LSB, 2014).

The IEA (2011) has estimated an average biomass (from waste) price of EUR 59 per dry tonne.[52] Since biomass is a central input to most biofuel production, this figure is very important. Naturally, there are variations depending on the type as well as the production path. IRENA (2013) has assessed the production costs of different biofuels. The world market price of biomass inputs for first generation biofuels assessed by IRENA are shown in Figure 4-8.[53] [54]

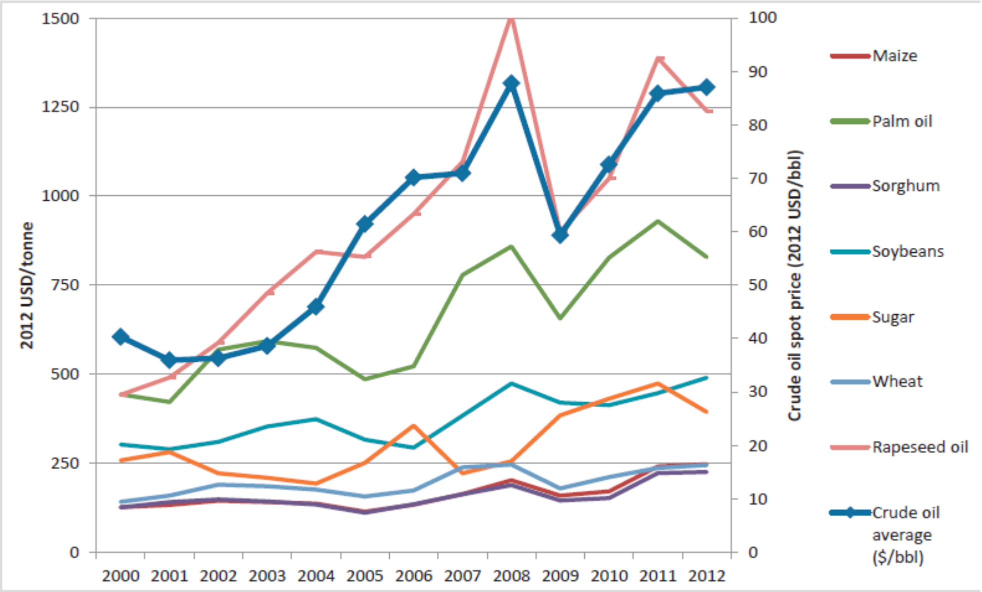

Figure 4-8: Global prices for food-based biofuel feedstocks and crude oil, 2000 to 2012. Source: IRENA (2013)

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[52] 75$ converted using an exchange rate of 0.79 Euro/$ per 24 October 2014. It is suggested that the figures should now be higher and in the range of 100 Euro per tonne.

[53] The price range for feedstocks goes up to 1185 Euro per ton (1500 $ converted to Euro using 0.79Euro/$).

[54] The assessment is mainly of relevance for the first generation biofuels, which currently is main used biofuel. However, this is likely to change in the future.

Using the inputs and calculations used by IRENA (2013) a summary of resulting conventional and advanced biofuels productions costs are as shown in Figure 4-9. The figure shows very low production costs for advanced biofuels such as "FT high temperature: 2020" at 0.8 – 1.0 USD/litre. Even though costs are based on lower biomass prices than can be sourced in Europe it gives a good indication what can be within reach when the industry has matured and become a global industry.

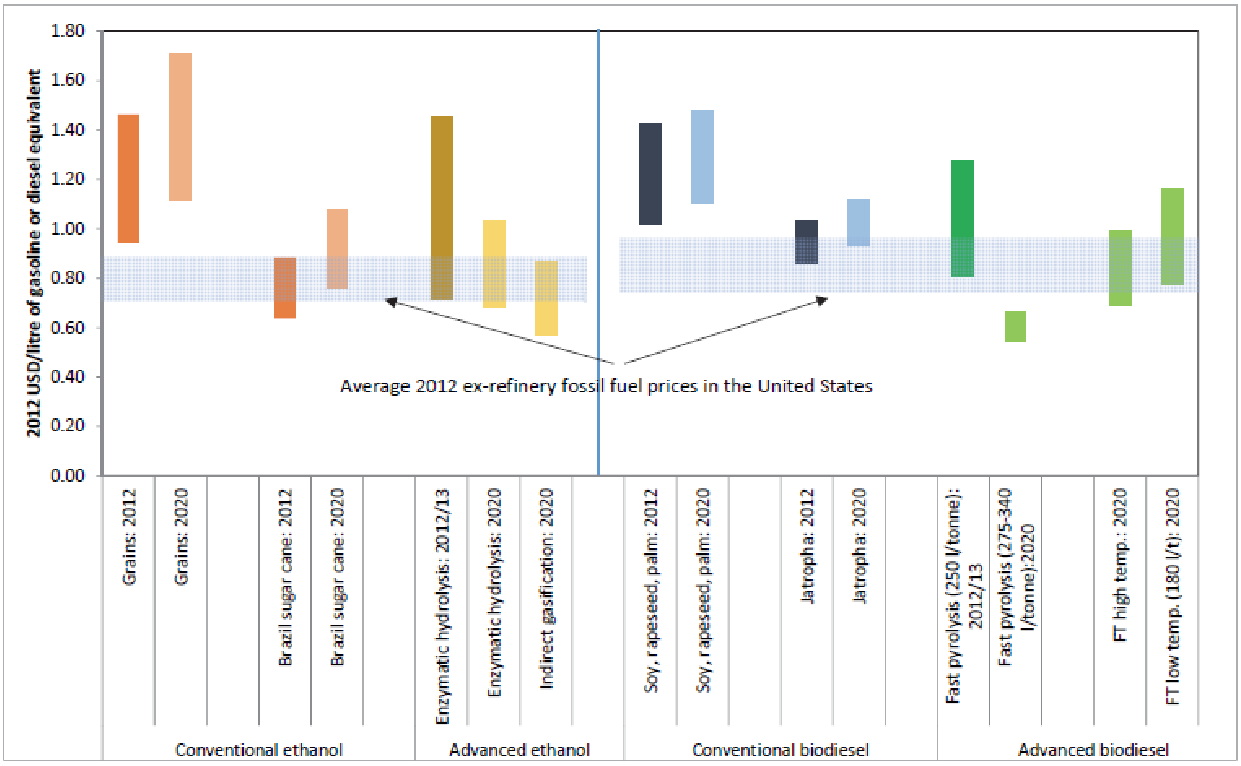

Figure 4-9: Summary of conventional and advanced biofuel production costs, 2012 and 2020. Source: Estimated by IRENA (2013) for the US market

The importance of costs of biofuels have changed, where first generation biofuels are very dependent on the price on the biomass, whereas for second and third generation biofuels it is to a much larger extent the operating and capital costs that determine the costs.

As an example from ethanol, the feedstock cost contribution is increasing as a proportion of the total, as other operating expense (OPEX) factors improve more quickly than ethanol yields per tonne feedstock. The IEA (2011) for example estimated that feedstock costs contributed 17% to the minimum ethanol selling price (MESP) in 2008. In 2016, it is further estimated that feedstock costs will comprise 34% of the total MESP.

In the longer term, reduced feedstock cost volatility can be an advantage for advanced biofuels that use lingo-cellulosic biomass sourced from energy crops, waste and residues[55] if the price is not constantly higher than conventional fuels. However,

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[55] IEA (2011) "Technology Roadmap: Biofuels for Transport". Referenced by Novozymes (2014) Information on cellulosic ethanol production.

the prices on the input biomass products and hence also the production costs can vary significantly even over short periods.

4.4 Natural Gas and biomethane

4.4.1 Definition and overall description

Natural gas and bio-methane are considered as a single fuel (CH4, methane). It can be sourced from fossil natural gas and as bio-methane from renewables or feedstock of non-biological (gasification) and biological (anaerobic digestion and gasification) origin, such as energy crops, agricultural wastes and residues, animal manure organic fraction of municipal waste, sewage sludge,. In addition to gasification of organic and non-organic feedstocks, it can also be produced as synthetic gas via the methanisation of hydrogen made from electrolysis of excise electricity (e-gas).

Natural gas and biomethane can be used in established combustion engines and existing Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) refuelling infrastructure, with performances equivalent to gasoline or diesel units and cleaner exhaust emissions. Natural gas and biomethane do not impose any problem to air quality and gas engines are notably more quiet than those running on conventional fuels. The technology is very mature and a range of EURO VI/6 cars, vans, buses and trucks exists (see 0). European manufacturers started to offer CNG passenger cars in the 1990´s. The engine technology has been constantly improved since offering a comfortable driving range of up to 500-900 km on CNG (plus reserve petrol) depending on vehicle configurations and well beyond 1.000 km total mileage, when also considering the petrol reserve tank. The technology is based on spark-ignition mono-fuel or bi-fuel engines (using gas as main fuel and only switching to the petrol reserve when the CNG has been used) and can also be used in compression ignition engines using diesel for ignition and gas as the main fuel (dual fuel and high pressure direction injection technology).

Biomethane from organic matter offers an extension and gradually increasing substitution for fossil natural gas. It can be mixed at any ratio with natural gas when used in natural gas vehicles. Currently standardisation work is ongoing in the European Committee for Standardisation (CEN TC 408 work programme). The work is both considering biomethane for injection into the natural gas network and the quality of both biomethane and natural gas at the filling station according to automotive fuel specifications. The automotive standard must deliver a gas quality at the refilling point that is suitable for use in current and future gas engine technologies. Harmonisation work on the purity requirements of methane as a transportation fuel, including on sulphur limits, is ongoing at industry level

Natural gas and biomethane could be also used in the form of Liquefied Natural Gas (LNG) for fuelling combustion engines in buses and trucks, boats and ships, the market mainly developed through dual fuel systems (engines burning together diesel and methane) and by now more and more LNG mono fuel systems with European type approval (ECE Regulation 110) are being introduced to the market. LNG increases the operability of commercial vehicles, as more energy can be stored on-board the vehicle, but the engine technology remains the same with CNG and LNG.

Natural gas and biomethane can be distributed through the existing natural gas pipeline infrastructure as compressed natural gas (CNG) in Europe or can be delivered using tanker ships in the form of LNG. Additional infrastructure, however, would be necessary to consolidate a basic EU filling stations network.

The infrastructure needs for LNG and CNG are different. For CNG, the natural gas needs to be compressed at 200 bar and dispensed from the current grid. For LNG, the natural gas needs to be handled as a cryogenic liquid, and could be sourced from LNG terminals or produced in liquefaction facilities. LNG and L-CNG stations able to supply both LNG and CNG have to be fed with LNG via heavy duty transport tank trucks equipped for handling cryogenic liquids.

The use of natural gas together with biomethane as transport fuel comes with a potential for reduction in carbon emissions. To achieve the full GHG emission reduction potential, it is essential to gradually increase the share of biomethane as an additive to natural gas, as the use of natural gas alone would imply limited TTW GHG emission reductions compared with the use of e.g. diesel fuels but considerable savings compared to gasoline. On the other hand, the use of biomethane will imply very low GHG emissions if produced e.g. through gasification of biomass (comparable to advanced biofuels) or even negative GHG emissions when produced from feedstocks which otherwise would emit methane during its decomposition process such as manure.. Carbon neutral mobility can be achieved when using bio- and synthetic methane without sacrificing the advantages of a conventional vehicle today in terms of comfortable operability and refuelling time.

4.4.2 **Availability and potential (2020-2030-2050)**

Natural gas has resources considerably exceeding those of crude oil, and there are vast accessible global reserves of unconventional gas. In addition, it is estimated that new drilling techniques could have increased the available resources, by up to a factor three in recent years.56 In 2013 the total gas consumption for the EU was 472 billion m³ , while considering that over 300 billion m³ (55%) were sourced from within European boarders (EUROGAS statistical report 2014), The global export capacity is set to rise by a third, from 290 million tonnes per year (mtpa) at the end of 2013 to nearly 400 mtpa by 2018. 57

The demand for gas as a transport fuel is set for rapid growth in Europe, while the EU´s gas consumption has shown a tendency to fall for various reasons, including increased production of renewable electricity, weakened competiveness versus coal, improved thermal insulation of buildings leading to reduced energy demand for heating, etc. The trend to use more gas in transport is set to expand and furthermore underpinned by the strong commitment of European vehicle manufacturers and a broad and continuously growing product offer.

The European Agency of Energy Regulators (ACER) forecasting model shows that gas consumption in the land transport sector is expected to play a significant role in the next decade, provided that the appropriate conditions for market development exist by 2025. The potential of CNG in road transport could hence increase to 23.90 billion m³ and LNG in road transport 34.5 billion m³, corresponding to 7.5% and 20% of the final energy consumption in transport respectively.

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[56] Based on information presented at US biogas conference.

[57] http://www.economist.com/news/business/21645212-promised-golden-age-gas-arrivingbut-consumers-are-cashing-well-producers.

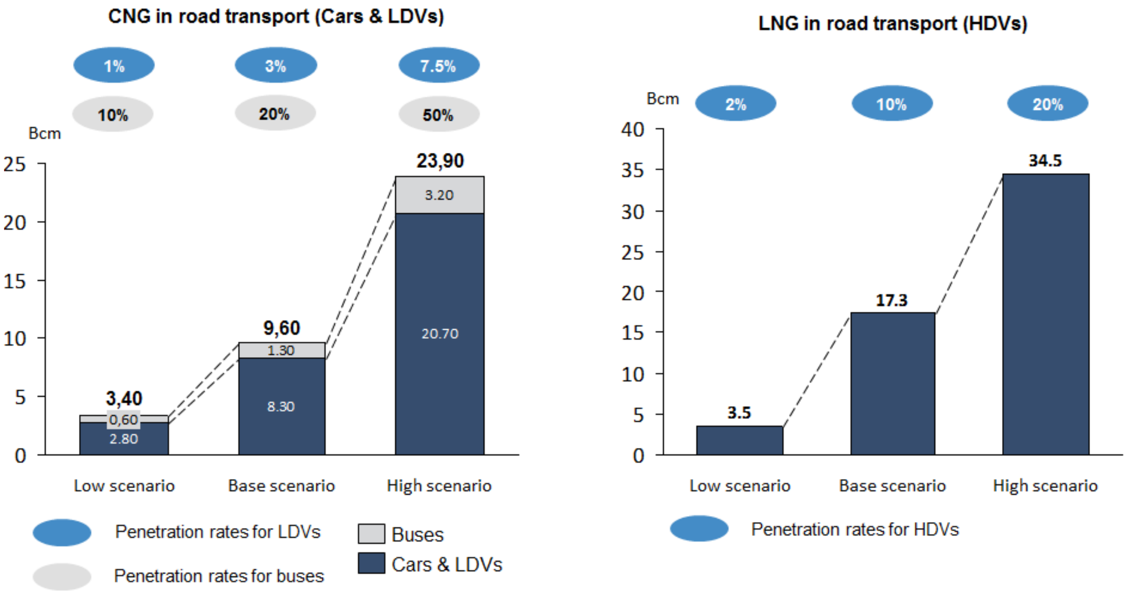

Figure 4-10: Regulatory implications of new developments in the gas supply chain. Source: ACER[58]

The level of total biomethane production foreseen for 2020 in the National Renewable Energy Action Plans to be about 12 billion m3 (in natural gas equivalents).59

The production potential of EU biomethane supply is calculated using a model that has been developed by the GreenGasGrids partners (EBA). The results are shown in Table 4-8.

Table 4-8: Maximal technical biomethane potential 2020-2030. Source: EBA, 2014

Source	***Billion m³***	***%***
Woody biomass	66	43.7 – 26.8
Herbaceous biomass	11	7.3 – 4.5
Wet biomass residues	26	17.2 – 10.6
Energy crops	48 – 143	31.8 – 58.1
Total	151 – 246	100.0

The supply of biomethane for all purposes has been estimated by EBA and is shown in Table 4-9. Nearly all of the biomethane produced in Europe is used for the production of electricity and heat, which corresponds to an annual biomethane production of approximately 1.3 billion m³. Only small quantities of biogas are upgraded to biomethane and used as a vehicle fuel so far. Notably only 10 EU Member States make use of the opportunity to use biomethane in transport. A high share of biomethane blends exist in Sweden, the Netherlands and Germany.

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[58] http://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/Regulatory%20Implications%20of%20New%20Developments%20in%20the%20Gas%20Supply%20Chain.pdf

[59] 1 m³ corresponds to 31.57 kwh

In 2013, 0.1 billion m3 of biomethane60 were consumed in transport in the EU, which represent 3% of the CNG/LNG used in transport (2.5 million toe). In 2013, there were 282 upgrading plants in 13 European countries (including Switzerland).

Table 4-9 Biomethane supply forecast (according to GGG methodology). Source: EBA, 2013

		Biomethane supply forecast				
		2012	2015	2020	2025	2030
Country	Population	TWh	TWh	TWh	TWh	TWh
Austria	8,477,000	0.08	0.23	0.89	1.55	2.14
Croatia	4,258,000		0.17	0.67	1.17	1.62
Germany	80,640,000	6.00	12.00	20.00	25.00	30.00
Italy	59,789,000		2.44	9.42	16.41	22.69
Hungary	9,894,000		0.02	1.03	3.08	7.18
Sweden	9,595,000	0.78	0.90	1.01	1.76	2.43
Netherlands	16,795,000	0.39	3.00	6.70	7.80	8.50
Slovakia	5,413,000		0.22	0.85	1.49	2.05
Spain	46,958,000		0.26	2.56	5.12	7.68
Poland	38,548,000		1.58	6.08	10.58	14.63
UK	64,231,000		3.50	13.50	23.50	32.50
France	63,820,000		1.00	10.00	20.00	30.00
Subtotal	408,418,000	7.25	25.32	72.71	117.44	161.42
Rest of Europe	90,000,000		5.57	16.00	25.84	35.51
Total	498,418,000	7.25	30.89	88.71	143.28	196.93

The consumption of natural gas (together with biomethane) as vehicle fuel is currently at the level of around 3 billion m^3/year (corresponding to 2.5 million toe). Partners participating in the Intelligent Energy Europe Green Gas Grids project (www.greengasgrids.eu), including the Natural Gas Vehicle Association and the European Biogas Association, expect that the share of natural gas/biomethane mixtures will increase to 10-15 billion m^3 by 2020 (reaching a 5% market share in the transport sector) and 25-30 billion m^3 by 2030[61] (reaching a 10% market share in the transport sector). The development of European biomethane production and trade might lead to a 10% renewable share of CNG/LNG vehicle fuel consumption. Grid injection is in practice in 11 European states (AT, CH, DE, DK, FI, FR, LU, NL, NO, SE, UK).

4.4.3 Emissions

The use of CNG as fuel will be a significant contributor to reducing GHG emissions if it is blended with biomethane.

JEC concludes that WTW GHG emissions for CNG lie between gasoline and diesel, but acknowledge that beyond 2020, greater engine efficiency gains are predicted meaning WTW GHG emissions will approach those of diesel (JEC 2014b). It is evident that the origin of the natural gas and the supply pathway are critical to the overall WTW

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[60] source: EBA. Corresponding to 498 ktoe
[61] Corresponding to 8.3 – 12.5 million toe and 20.8 – 25 million ton respectively

energy and GHG balance.[62] However, it has been argued that several scenarios currently being considered by JEC do not necessarily reflect reality and existing practices may be inconsistent when taking into account that different pathways have been used for natural gas.

Biomethane based on manure implies negative WTW GHG emissions, whereas using energy crops for biomethane production have a low carbon footprint due to their high production yields, which can be of up to twice the yield per hectare compared to other crops destined to produce liquid biofuels. Therefore, under right conditions biomethane from energy crops can save 70% in emissions compared with conventional diesel. Synthetic biomethane has nearly zero emissions. Manure has a very low methanogenic potential, whereas biomethane injection requires high level of production. Economy of scale will need to use energy crops to increase biogas production, because they are 6 to 8 folds more methanogenic. Besides it is usually necessary to mix manure and crops which are complementary to produce biogas.

Summaries of the GHG WTT, WTW and TTW emissions from the JEC (2014b) report for CNG and biomethane are given in Table 4-10. The negative GHG emissions for some biomethane paths are due to the de-gasification of e.g. manure, which is then not emitting GHG when distributed as fertilizer on fields.

New technologies and emissions pathways to be taken into account include CNG-hybrids, first successful examples of CNG-hybrid buses in operation already exist in Spain[63] and Sweden[64].

While JEC considers the average TTW CO_2 reduction potential for CNG passenger cars to be around 18% compared with petrol engines (based on 2010), today TTW emissions exceeding 30% with state of the art natural gas engines are achievable. As a reference the current Golf TGI has the same engine power in both petrol and CNG mode (110hp) and the CO2 emissions of the TGI are 94g/km, while they are 124g/km driven in petrol mode (32% higher).[65]

Considering Euro VI CNG and LNG fuelled HDVs, the homologation data indicates a lower GHG emission of up to 10% (e.g. as reported by IVECO, Daimler, and Scania).

Table 4-10: The range of WTT, WTW and TTW GHG emissions for CNG and biomethane for 2010. Source: JEC (2014b) Appendix 1

Alternative fuel	WTT g CO_2 /km	TTW g CO_2/km	WTW g CO_2 /km
CNG, EU-Mix	30	132	163
Biomethane	- 290 to -33	132	-158 to 99
Conventional gasoline	29	156	185
Conventional diesel	25	120	145

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[62] The JEC data are contested by other sources, in particular for natural gas and biomethane. There are a number of other studies pointing at skewnesses in the data as well as gas leaking, which the JEC is not considering. However, this report is not trying to assess these differences.

[63] http://ec.europa.eu/environment/gpp/pdf/news_alert/Issue39_Case_Study83_Madrid_alternative_vehicles.pdf

[64] http://www.ngvglobal.com/van-hool-delivers-first-gas-hybrid-tram-bus-to-malmo-0321

[65] www.volkswagen.de

The use of natural gas and biomethane has low pollutant emission levels (mainly NOx), almost zero SOX emissions, and no particulate matter emissions close to zero. The reduced noise is another advantage compared to diesel oil.

4.4.4 Energy efficiency

The overall GHG balance of gas for transport can be optimised by maximising the conversion efficiency, by improving energy efficiency of the plant or by improving engine energy efficiency, yet not fully exploited.

JEC (2014b) estimated the energy efficiency from CNG vehicles for 2010 and with 2020+ projection. The estimations reveal that greater energy efficiency for CNG vehicles will be seen towards 2020. In fact, natural gas is the only alternative fuel able to meet the efficiency of diesel engines when used in a spark ignition combustion engines (efficiency gap of petrol and diesel engines approx. 15%). Manufacturers increasingly focus on CNG and major technological steps can be seen in current and next engines generations, improving energy efficiency and performance.

The 2010 estimated energy consumption by CNG and biomethane WTT, TTW and WTW as well as the WTW share from non-fossil origin are shown in Table 4-11. The WTT figures here include energy consumed also to produce the crop (JEC 2014a). Although the overall energy input for production of biogas and synthetic methane is high, much of this energy is of renewable origin and so the GHG emissions are very low as shown above, especially if biomass from waste is used for biogas.

Table 4-11: The range of WTT, WTW and TTW energy consumptions for different CNG and biomethane for 2010. Source: JEC (2014b) Appendix 1[66]

Alternative fuel	WTT MJ /100 km	TTW MJ / 100/ km	WTW MJ / 100 /km	WTW from non-fossil fuels MJ /100 km
CNG EU-Mix[67] NG supply	38	232	271	1 - 8
Biomethane	231 - 503	232	463 - 736	421 - 701
Conventional gasoline	39	211	250	0
Conventional diesel	33	163	196	0

The JEC study is as mentioned, referring to 2010 standards of vehicles. The energy efficiency and performance of the latest powertrain technology in CNG CNG vehicles is practically the same compared to those of petrol vehicles and even better in optimised gas engines due to the higher compression ratio when running on gas exclusively, without adaptation to be able to burn petrol in bi-fuel engines. Next Natural Gas engines have the potential to meet the efficiency of compression ignition engines. Gas engines are very often special developments with different engine output compared with petrol or diesel equivalents.

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[66] Again the energy consumption figures especially for natural and biogas vehicles are contested. In the case of e.g. LD bi-fuel vehicles, the CNG engine is just the same as the gasoline engine (same Otto cycle, same efficiency); so also the energy consumption MUST be the same.

[67] The EU-mix refers to the average energy consumed to deliver CNG

4.4.5 Maturity of technology

Regarding biomethane, the main barriers to market penetration are the higher cost of biomethane in comparison with natural gas, the delays in the adoption of the standard being developed by CEN/TC408 for natural gas and biomethane for use in transport and biomethane for injection in the natural gas grid.

New LNG production capacity now decided and under construction is small. The large project in Australia is earmarked for the Far East as is some smaller new capacities from the Persian Gulf. Currently the EU is only using 20% of the existing capacity in the existing terminals.

The construction of LNG terminals in the EU will be key for the diversification of energy supply and for the adoption of natural gas as fuel for vehicles. Natural gas from fossil sources and later increasingly also from biomass, waste or from power-to-gas technology has a relevant share.[68] Power-to-gas technology will allow unused renewable electricity to be converted into synthetic natural gas and used in CNG vehicles, and existing combustion technologies offer a tremendous flexibility for the integration of renewable energy sources, even though at low energy efficiencies. For this and other reasons, vehicle manufacturers focus on two major technology trends in the future, natural gas and electric powertrains and a combination of both in the future.

Notably, the European manufacturing industry is global leader in the development and production of CNG and LNG vehicles and infrastructures. The entire technology, including components, is Original Equipment Manufacturer (OEM) products or in-house developments.

Maturity of NG engine technology is relatively high with particular research needs regarding robust direct injection and ignition systems for homogeneous and stratified combustion. In case of lean burn approaches specific developments will have to be addressed to the DeNOx after-treatment, the conversion of current modern diesel engines into NG engines with minor hardware modification, gas quality sensors for monitoring gas composition variations and compatibility of lubricants with gas engine technology.

4.4.6 Production cost of fuels

Biomethane costs are estimated in IEA Bioenergy (2014) from which Figure 4-11 is shown. The costs are shown for different elements and for different production alternatives. The costs are compared with the expected price range for CNG in 2030. According to the study, the total biomethane costs today are between 6 and 10 Euro cent per kWh compared to an expected CNG price between 4 and 6 Euro cent per kWh.

The main costs are related to the production of biogas, but there are also costs related to upgrading the biogas to biomethane. All the calculations indicate that biomethane production costs will carry on to exceed the expected future CNG price, unless there will be scale effect and stronger incentives.

It has to be taken into account that natural gas and biomethane are measured and sold in kilograms (kg) and not in litre like most fuels, the energy content in one kilogram of natural gas is either equivalent to 1.3 litre of diesel, 1.5 litre of petrol or 2.1 litre of LPG. Better comparability of fuel prices to the customer is therefore of

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[68] ERTRAC Roadmap "Energy Carriers for Powertrains, http://www.ngvaeurope.eu/downloads/news/Roadmap_Energy_carriers_for_powertrains.pdf

major importance, which is also being taken into account by Directive 94/EU/2014 aiming at a litre equivalent pricing model making it possible to compare the real energy price of fuels whether in kWh, kg or litre.

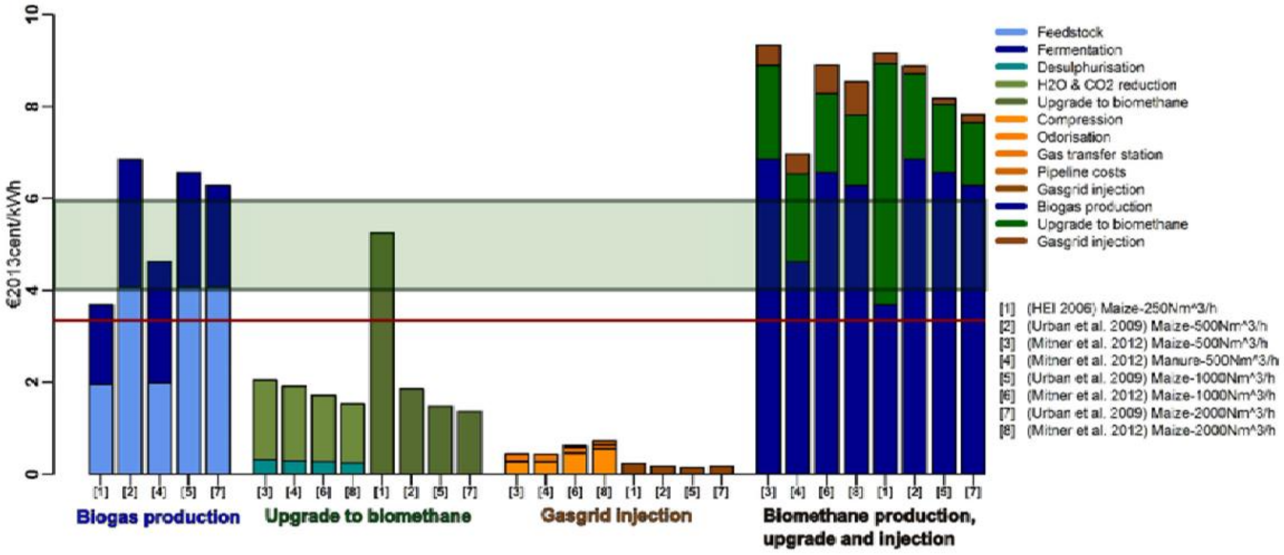

Figure 4-11: Averaged specific biomethane deployment costs acquired from literature broken down into components: The vertical red line shows the reference European average natural gas price of 2012 (Eurostat Database 2013) and the green shaded part gives a natural gas price range for 2030 (Sebi et al. 2013)). The tick marks indicate the respective literature, feedstock and size of the biomethane production. Source: IEA Bioenergy (2014)[69]

The costs of natural gas and biomethane are linked to the fluctuations of the market. Other costs to be considered are those related to infrastructures (pipelines, LNG terminals).

Production costs for biomethane is relying on both the investments and operational costs of the production plants.

Typical investment costs of network connection stations are a function of feed-in capacity. Total capital expenditure (CAPEX) (€/year) including compression, regulation and grid connection: 1,720,000 for a capacity of 700 m3 STP/h.[70]

Typical operational costs of network connection stations are a function of feed-in capacity. Total operational expenditure (OPEX) (€/year): 274,400 for a capacity of 700 m3 STP/h

This leads to total production costs of biomethane of 7-9 €c/kWh for a plant with feed-in capacity of 400 Nm³ /h and 6-8 €c/kWh for a production plant with capacity of 700 Nm³ /h.

Both the production costs and fuel price of biomethane very much depends on the subsidy and tax scheme in each country, there is no commonly used approach in Europe so far. When also taking into account that biomethane is generally blended

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[69] IEA Bioenergy (2014) Biomethane – status and factors affecting market development and trade. Edited by Martin Junginger and David Baxter for IAE Bioenergy Task 37 and 40.

[70] Source: W. Urban (2013) The Biogas Handbook: Biomethane injection into natural gas networks

with natural gas, the comparison with CNG will be difficult. However, it can be estimated that the average premium for biomethane would range between 0.10-0.20 Euro cents/kg at the pump.

Table 4-12: OPEX according to plant operators Installation size in m3 i.N./h. Source: Adler et al. (2014). Leitfaden Biogasaufbereitung und –einspeisung. 5. Vollständig überarbeitete Auflage. Fachagentur Nachwachsende Rohstoffe e.V. (FNR). P.108

http://mediathek.fnr.de/media/downloadable/files/samples/l/e/leitfaden_biogaseinspeisung-druck-web.pdf

Operational costs in €/p. a.	**250**	**350**	**400**	**500**	**700**	**1400**	**2000**	**2800**
Axiom	-	-	220.000	-	339.100	-	-	-
Carbotech	-	-	154.500	-	238.500	386.000	501.000	598.000
Greenlane	-	-	153.990	-	251.200	349.600	449.800	542.800
Haase	118.000	-	-	182.300	246.900	421.800	543.900	663.000
Malmberg	-	137.100	-	-	227.700	393.800	486.400	-
MT Biomethane	-	-	-	246.700	333.700	607.500	824.800	-

4.5 Synthetic Fuels and Paraffinic Fuels

4.5.1 Definition and overall description

Many of the synthetic fuels could also have been included as a biofuel. For this report a distinction between them is kept however. Synthetic fuels as described here are classified as advanced biofuels or second generation biofuels when produced from renewable energy sources such as biomass. Therefore Section 4.3 and Section 4.5 overlap on several aspects.

Synthetic fuels can be used as substitutes for diesel, gasoline and jet fuel assuming the finished fuels meet the appropriate standards. The synthetic fuels can be produced from different feedstock, converting biomass, gas, coal or plastic waste into liquid fuels, methane and dimethyl ether (DME). Synthetic paraffinic diesel fuels, such as hydrotreated vegetable oils (HVO), Fischer-Tropsch diesel (FT) etc., are fungible and can be blended into fossil diesel fuel at very high blending ratios, or can be used in all existing or future diesel vehicles. Therefore, these fuels can be distributed, stored and used with the existing infrastructure. Synthetic fuels substituting gasoline, such as methanol and other alcohols, can be blended with gasoline and can be technically used with today's vehicle technology with minor adaptions. Methanol (produced from coal) is already widely used in China (M15, M30, M85) and allowed to up to 3% in EU (EN228); however acceptance in automotive industries is variable. Pure methanol is toxic, and special precautions need to be taken when used in its pure form. Methanol can also be used for waterborne transport for inland as well as for short-sea shipping. Synthetic and paraffinic fuels have the potential to reduce the use of oil sources in the energy supply to transport[71].

The main diesel standard in the EU is EN 590 2013. Blends of up to around 30% paraffinic fuels and diesel will meet density limits set in EN 590. Unblended (100%) paraffinic fuel meets prEN 15940 and all EN 590 standard values except density. Using paraffinic fuels in blending exceeding the density limit set in EN 590 may occasionally require some calibration of the engine to ensure that regulated emission limits are

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[71] As defined in Recital 10 of the CPT Directive

met. Appropriate maintenance as recommended by vehicle manufacturer may be required when switching to a different fuel. These characteristics allow seamless compatibility and durability of engines, fuel systems, exhaust after-treatment device, and engine oil.

4.5.2 Availability and potential (2020-2030-2050)

Gas to Liquid (GTL) and HVO are in an early commercial stage. If Europe developed a strong demand for paraffinic fuels, this demand pull might encourage investment in additional production plants assuming the economics are attractive.

Production capacity globally is already around 5.7 million tonnes GTL fuels per year and close to 3 million tonnes of HVO per year (with the aim to increase capacity by 15% to 2.3 million tonnes per year by 2015).[72] Several new GTL plants have been announced, many taking advantage of the shale gas boom in the USA among other locations. However, this production mainly takes place outside Europe. The GTL plants are in Qatar, Malaysia and the USA. There is one pilot plant in Europe, in the Netherlands.

HVO of a similar paraffinic nature, can be produced by hydrotreating plant oils and animal fats. Global HVO feedstocks are currently the same as for FAME (biodiesel) with its current production being 3 Mt/y. A growing supply of algal oil, HVO could constitute a significant share of transport fuels by 2030, with production in the order of 25 Mt/y, and in the order of 60 Mt/y by 2050.

Biomass to liquid (BTL) can be produced from a wide range of biomass feedstock by applying the same advanced synthesis processes developed for GTL. The production of BTL is at pilot plant level and a strong investment is needed to enable a shift to commercial scale.

DME can be produced in the same type of upstream processes as BTL but the synthesis gas produced from the gasification process is instead converted to methanol and then further to DME via dehydration. .

Methanol is one of the most common chemicals globally with an annual capacity of about 95 million metric tons (IHS Chemical). According to a new IHS global market study, driven by Chinese demand growth, global methanol demand increased 23% during the two-year period of 2010 to 2012, and annual demand for the product is expected to increase by more than 9% per annum from 61 million metric tons (MMT) in 2012, to a level of 146 MMT in 2022.

The large availability of cheap shale gas in the US has boosted the methanol industry and resulted in a large number of projects as can be seen in Figure 4-12. (Methanol Institute). Production is expected to increase from 4 to over 17 million tons of methanol annually between 2015 and 2020.

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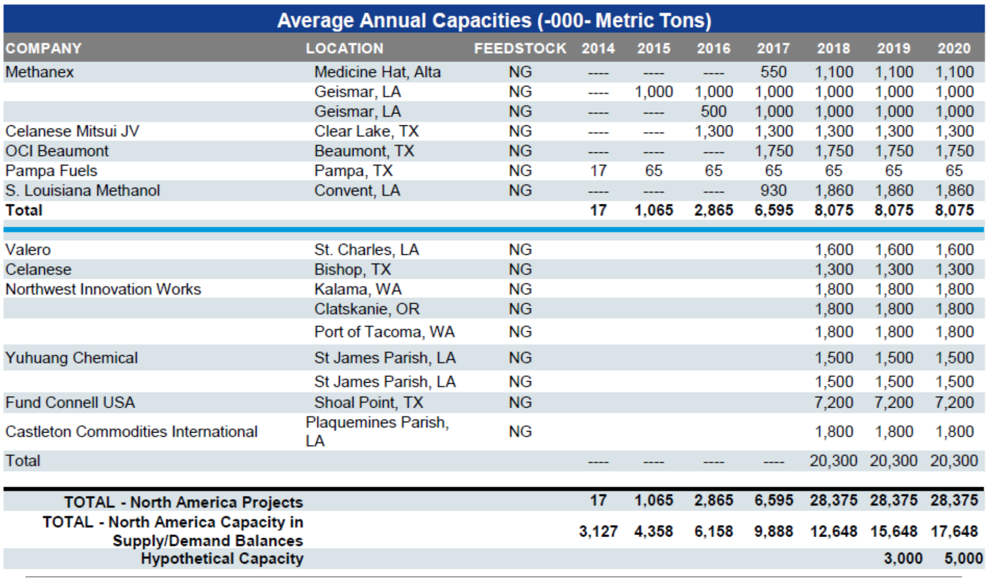
[72] As reported by ASFE, EGFTF meeting May 2014; also http://www.synthetic-fuels.eu/parafinnic-fuels/commercial-availability



Average Annual Capacities (-000- Metric Tons)									
COMPANY	LOCATION	FEEDSTOCK	2014	2015	2016	2017	2018	2019	2020
Methanex	Medicine Hat, Alta	NG	----	----	----	550	1,100	1,100	1,100
	Geismar, LA	NG	----	1,000	1,000	1,000	1,000	1,000	1,000
	Geismar, LA	NG	----	----	500	1,000	1,000	1,000	1,000
Celanese Mitsui JV	Clear Lake, TX	NG	----	----	1,300	1,300	1,300	1,300	1,300
OCI Beaumont	Beaumont, TX	NG	----	----	----	1,750	1,750	1,750	1,750
Pampa Fuels	Pampa, TX	NG	17	65	65	65	65	65	65
S. Louisiana Methanol	Convent, LA	NG	----	----	----	930	1,860	1,860	1,860
Total			**17**	**1,065**	**2,865**	**6,595**	**8,075**	**8,075**	**8,075**
Valero	St. Charles, LA	NG					1,600	1,600	1,600
Celanese	Bishop, TX	NG					1,300	1,300	1,300
Northwest Innovation Works	Kalama, WA	NG					1,800	1,800	1,800
	Clatskanie, OR	NG					1,800	1,800	1,800
	Port of Tacoma, WA	NG					1,800	1,800	1,800
Yuhuang Chemical	St James Parish, LA	NG					1,500	1,500	1,500
	St James Parish, LA	NG					1,500	1,500	1,500
Fund Connell USA	Shoal Point, TX	NG					7,200	7,200	7,200
Castleton Commodities International	Plaquemines Parish, LA	NG					1,800	1,800	1,800
Total			----	----	----	----	20,300	20,300	20,300
TOTAL - North America Projects			**17**	**1,065**	**2,865**	**6,595**	**28,375**	**28,375**	**28,375**
TOTAL - North America Capacity in Supply/Demand Balances			**3,127**	**4,358**	**6,158**	**9,888**	**12,648**	**15,648**	**17,648**
Hypothetical Capacity								**3,000**	**5,000**

Figure 4-12: US based methanol projects. Source: Methanol Institute

4.5.3 **Emissions**

The JEC (2014b) report has considered three sources and manufacturing processes in relation to synthetic (diesel) fuels:

- From natural gas (known as Gas-to-Liquids or GTL)
- From coal (known as Coal-to-Liquids or CTL)
- From woody biomass (known as Biomass-to-Liquids or BTL).

Moreover, also DME processes are considered.

The GTL pathway has GHG emissions comparable to conventional diesel. The CTL pathway has significantly higher GHG emissions than conventional fossil fuel pathways, but this could be improved by CO_2 capturing in the plant. Only HVO and BTL fuels provide scope for GHG emissions reduction, with HVO offering reductions of 40 to 90% and BTL from 60 to 90%, compared with conventional oil-derived fuels. These results, however, assume 100% HVO or BTL which may not meet EN590 diesel specification in all properties.

The use of methanol in a combustion engine will for some line of productions (e.g. GTL), result in GHG emissions at the same level as gasoline and at a slightly higher level than diesel. Furthermore, the use of blends of renewable methanol with methanol would permit even more significant rates of GHG emission reduction.[73]

Table 4-13: The range of WTT, TTW and WTW GHG emissions for different synthetic fuels for 2010. Source: JEC (2014b) Appendix 1

Alternative fuel	**WTT g CO_2 /km**	**TTW g CO_2/km**	**WTW g CO_2 /km**
HVO	-111 to -22	116	5 – 94

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[73] JEC, 2014b, Appendix 2, Table 1.5. However, the figures are related to the Well to Tank emissions. Emissions on Tank to Wheel are similar for methanol and gasoline/diesel.

GTL	22 - 38	116	138 – 154
CTL	65 - 211	116	181 – 328
Wood (Syndiesel)	-104 to -111	116	5 – 12
DME (natural gas / Coal / Wood)	38 / 218 / -104	117	154 / 334 / 12
Conventional gasoline	29	156	185
Conventional diesel	25	120	145

Table 4-12 shows the range of 2010 WTT, WTW and TWT GHG emissions as reported by JEC (2014b). Depending on the production path, there are quite large differences.

Paraffinic fuels also contribute to improving air quality. Paraffinic fuels have high cetane levels and are practically free from aromatics and sulphur. The comparison of emission levels of paraffinic fuels with conventional diesel from Euro standards II, III, IV and EEV vehicles are shown in Figure 4-11.

The reduction levels are higher for heavy-duty vehicles generally across all emissions. There are no comparisons for Euro VI vehicles.

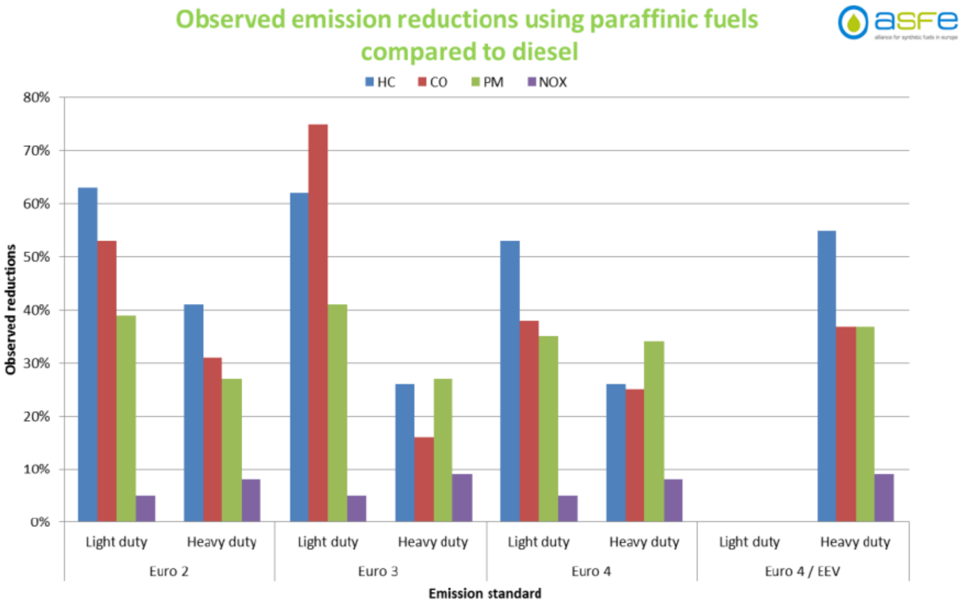

Figure 4-13 Paraffinic fuels, emission reductions. Source: ASFE, 2014

Looking at methanol, Wärtsilä[74] has presented some emission results concerning local air pollutants measured from ship engines. According to the test results they have obtained, an engine running on methanol emits between 3 and 5 g/kWh NO_X, less than 1 g/kwh of CO and THC; the engine is also very low on particles. Sulphur emission reduction are at almost zero levels. However, methanol-fuelled engines use a pilot fuel, which is responsible for some pm emissions and some trace emissions of sulphur. There is no similar information about emissions for other modes of transport or other synthetic or paraffinic fuels.

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[74] Lennart Haraldson, Wärtsilä Use of methanol in internal combustion engines – a status review. Presentation at the PROMSUS Conference, May 6 2014, Gothenburg, Sweden

4.5.4 Energy efficiency

Paraffinic fuels, syn-diesel and DME are all notably more energy-intensive than conventional diesel fuel according to JEC (2014b). The combined process of primary energy conversion and FT synthesis is energy-intensive; in particular, more energy intensive for coal and wood than for natural gas. Energy consumption for HVO is in the range of 188-570 MJ/100 km, for syn-diesel it is between 265 and 423 MJ/100 km, and for DME the energy consumption is between 265 and 356 MJ/100 km. The comparable figure for conventional gasoline is 250 MJ/100 km and for diesel it is 196 MJ/100 km. All the figures are WTW figures. The WTT energy consumption figures are shown together with TTW and WTW figures in Table 4-14.

Table 4-14: WTT, TTW and WTW energy consumption figures for 2010. Source: JEC (2014b)

Alternative fuel	WTT MJ/100km	TTW MJ/ 100 km	WTW MJ/ 100 km	WTW from non-fossil fuels MJ /100 km
HVO	26 – 407	163	188-570	167 – 504
GTL	103 - 115	163	265 – 277	1
CTL	157 - 171	163	319 – 333	5
BTL	148-195	163	357	347
DME (natural gas/Coal/wood)	92 / 163 / 184	172 / 172 / 172	264 /334 / 356	2 / 12 / 346

The Wärtsilä tests for ship engines[75] show that the methanol engine presents the same efficiency as a comparable engine running on diesel.

4.5.5 Maturity of technology

The European CEN specification for paraffinic fuels has now been upgraded from a Technical Specification (TS) to a "prEN" specification, CEN prEN 15940 – the 3rd stage in a multi-year process before a full "EN" specification is given. The existence of reference specifications like CEN prEN 15940 for paraffinic fuels enables vehicle manufacturers and regulators a more scientific and consistent way of referring to GTL, HVO and BTL fuels, and sets a high standard for paraffinic fuels.

A technical standard for the drop-in jet fuel is also defined. This is ASTM D7566, a general specification for semi synthetic jet fuel (fossil and biofuel). In 2009, FT kerosene (up to 50% blend) was certified under this specification, followed by HVO Kerosene in 2011 (called HEFA, certified up to 50% blend). A third pathway (Direct Sugar to Hydrocarbons, producing mainly farnesane) has been certified in late 2014 (up to 50% blend) and SIP in 2014.

Commercial HVO and GTL plants exist both in the EU and in other world regions, whereas BTL technology is still at a pilot stage.

Presently, the different fuels are at different maturity levels as illustrated by Figure 4-14. GTL and HVO from vegetables and waste fat are already today market ready, whereas BTL and notably HVO from algae and microbes, and STL[76] are expected to be ready for the market in the longer term.

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[75] See footnote 74
[76] Solar to Liquid

The GTL process is technically well established, although the economics has, in the past, not been sufficiently favourable for large-scale development to occur. This has been changing in recent years with a combination of technological advances and more favourable economics, and a number of large-scale plants have been built. All such plants are located near a major gas field usually where the only alternatives for bringing gas to market are LNG and methanol. In this situation, any captured CO_2 could be conveniently re-injected into the gas field. (JEC, 2014b).

Coal gasification, CTL, is a well-understood process that can be coupled to FT synthesis to deliver products very similar to GTL. There are a number of plants running in China today, but very few plants in operation elsewhere. These schemes are attracting a lot of interest especially in combination with CO_2 capture and storage. (JEC, 2014b)

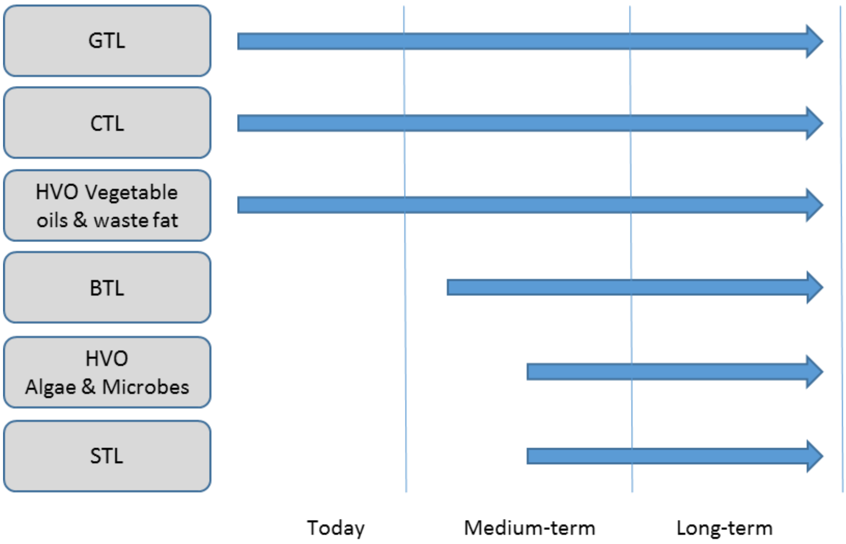

Figure 4-14: The maturity of different synthetic fuels. Source: ASFE, 2014

BTL path The wood gasification process is similar to the gasification process of gas and coal although using biomass creates specific issues related to, among other things, the mineral content of certain biomass feedstocks, problems of slagging, etc., each biomass feed creating different problems. Adaptation of the FT synthesis to syngas of different origins revolves around purity, cleanliness and CO/H_2 ratio of the gas.

Another challenge is the scale at which such processes could be practically used. Integrated gasification and FT plants are complex and expensive with any feedstock and benefit greatly from economies of scale. Biomass, as a low energy density and relatively dispersed feedstock, does not fit well within the traditional industrial model, and novel ways have to be developed to find acceptable compromises.

The current search for alternative transport fuels has increased the level of interest for the BTL route and a number of pilot and demonstration projects have been pursued although no concrete route to a commercial scale project has been pioneered so far. These will always be complex engineering projects, for which many practical problems need to be resolved before they become reliable and commercially viable. The major challenges for achieving this should not be underestimated. The potential rewards from these processes in terms of feed flexibility, quality of the products and very low GHG emissions justify further research and development. (JEC, 2014b).

Methanol is synthesised from syngas and can therefore be produced from a range of feedstocks. DME is dehydrated methanol and DME production is therefore mostly seen as a simple add on process at the end of a methanol plant. The synthesis process is thus very similar to that of methanol and has a similar efficiency; somewhat higher than the efficiency of the synthetic hydrocarbon processes. Methanol and DME production technology is very mature industry with a large number of plants all around the world utilising mostly coal (China) and natural gas as feedstocks.

The most likely feedstock in the short term is natural gas, but coal or wood can also be envisaged. Should DME become a major fuel, future plants could be built considerably smaller than GTL and LNG plants as the investment intensity is comparably low also for plants, which are only a fraction of the size of GTL and LNG plants. This leads to that DME (as well as methanol) plants can be built on smaller natural gas fields, those which are too small to hose large GTL and LNG installations . CCS could be conveniently applied in this case, particularly because CO_2 has to be separated in the synthesis process and is therefore already “captured”. However, because methanol and DME synthesis is simpler than FT, smaller plants located in Europe and fed with imported gas can also be envisaged.

Audi has together with Climeworks and Sunfire set up a pilot plant for e-diesel production. In the test plant in Dresden e-diesel will be produced from CO_2, water and electricity in a power-to-liquid principle.

Sun-to-Liquid (STL) is fully drop-in synthetic fuel produced from CO_2 and water using concentrated sunlight as energy source.

STL was successfully demonstrated with the first ever production of synthesised “solar” jet fuel on 28 April 2014, in the course of the EU-funded SOLAR-JET project.

Solar to power or geothermal to power or wind to power can all be combined with FT or methanol or methane or DME.

This **solar path** appears promising as it is based on the use of potentially unlimited sustainable feedstock not competing with food. At the horizon 2020/2030, it might progressively allow the production at large scale of carbon neutral synthetic drop-in fuels, in particular kerosene, and hence reduce significantly the global CO_2 emissions from aviation and more widely from transport.

This new pathway is attractive, also as it relies largely on mature technologies such as industrial Fischer-Tropsch reactors or on “close-to mature” technologies such as Concentrated Solar Power (CSP) already used in large plants for electricity production. Moreover, in the case of commercial aviation, Fischer-Tropsch-derived kerosene is already approved and directly usable in existing aircraft without any modifications, which is a substantial advantage for this final product as the approval process is long and costly.

The most innovative part of the overall process, which still requires additional development in the coming 10 years, is the thermochemical reactor to convert simultaneously carbon dioxide and water to syngas. This is obtained by means of a redox cycle using metal-oxide based materials together with concentrated sunlight as energy source to provide the high temperatures necessary to the thermo-chemical reactions. Further research will focus on enhancing the overall solar-to-fuel energy conversion efficiency and system integration, which is key to ensuring the future economic viability of the process.

Finally, this solar thermochemical pathway shows a quasi-perfect complementarity with the biomass-based route. Optimal locations for STL in terms of DNI (Direct Normal Irradiance) are preferably in arid/dessert areas, which are normally used neither for agriculture nor for biomass production. Furthermore, the STL pathway could become a significant economic opportunity for the sunniest/arid regions or countries, which are often, also the most economically challenged.

Regarding the maturity of compression ignition engine technologies it can be stated that paraffinic fuels on the one hand lead to excellent combustion properties and typically produce lower emissions. On the other hand, due to the lower densities and worse lubrication properties of paraffinic fuels, the fuel injection systems have to be adapted. But there is no particular research need seen.

In case of spark ignition engines, the use of synthetic fuels in direct injection technologies could offer the potential to positively influence particulates emissions. E.g., fuel formulations without aromatics along with dedicated combustion processes could be an interesting option. In view of new combustion processes, lighter fractions with higher volatility and lower Cetane number could have the potential for extending Low Temperature Combustion regime (LTC), thus, allowing to achieve simultaneously lower nitrogen oxides and particles emissions.

4.5.6 Production cost of fuels

Product costs are based on production, logistic and market factors, and may change over time. Currently neat GTL fuel is available in the Netherlands at prices similar to but higher than diesel. The main barrier to the use of BTL and HVO is their high costs. Reducing investment cost is critical, as current plants are challenged by relatively high capital costs. BTL commercial plants, however, are still awaiting start up, and reliable data on costs are currently unavailable. The current costs for GTL and CTL will significantly increase if CO_2 is captured in the plant.

Methanol prices are competitive with gasoline prices, even when considered on an energy equivalent basis (Bromberg and Cheng 2010). In fact, methanol prices in China are considerably lower than gasoline on an energy equivalent basis, and this has been a key factor driving the strong growth of methanol as a transportation fuel in China over the last years.

4.6 Liquefied Petroleum Gas

4.6.1 Definition and overall description

LPG is a mixture of hydrocarbon fuels: propane, butane and in small percentages propylene and butylene. LPG occurs naturally in natural gas and petroleum and is recovered from their extraction and refining. In cold weather, more propane is used in proportion 60-40%, while at higher temperatures it may contain more butane (up to 60%), because of the lower evaporation point of butane at low temperatures.

An important difference between LPG and conventional vehicles is the method of fuel storage. LPG is gaseous at room temperature, but can be liquefied at moderate pressures. LPG is maintained liquid in pressurized storage tanks throughout the entire infrastructure to the fuelling station as well as in the vehicle. The liquid LPG is ultimately converted to its gaseous state in the vehicle's engine.

LPG can be used for road transport covering short, medium and long distances in Light Duty Vehicles (LDV) and Heavy Duty Vehicles (HDV), but is also suitable for maritime and inland waterways. LPG road vehicles currently represent almost 3% of the European fleet.

4.6.2 Availability and potential (2020-2030-2050)

Co-produced with natural gas and petroleum products as well as having alternative pathways, the availability of LPG is expected to remain high for the considered timeframe.

The following graphic illustrates the different synthesis paths for LPG from biomass as a co-product of other processes.

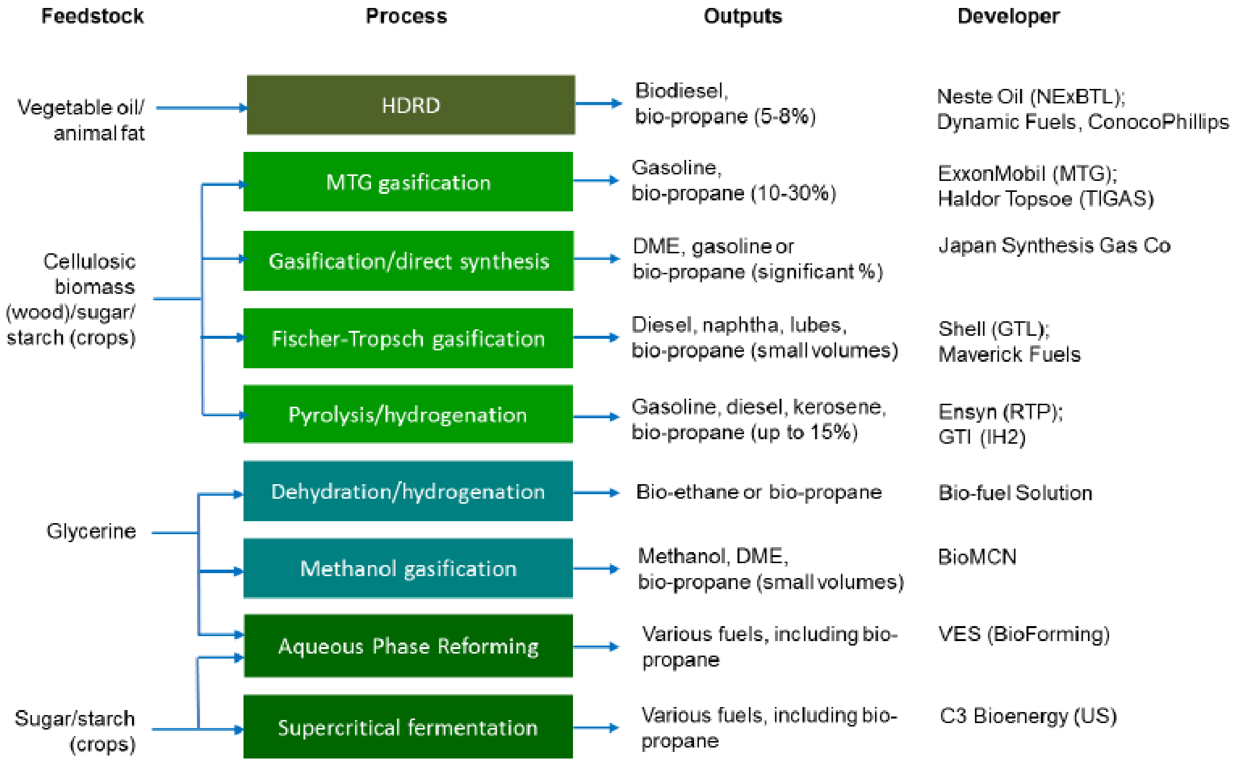

Figure 4-15: LPG potential. Source: AEGPL, 2014

Besides the generation of bio-LPG, other synthesis processes equally yield a certain percentage of renewable LPG, for instance the synthesis of liquid fuels out of natural gas (gas to liquids, GTL). In the future, wind power is planned to be used to synthesise liquid fuels by using excess electricity and capturing carbon from the atmosphere in form of CO_2 (power to liquids, PTL). The amounts of LPG generated through these processes depend strongly on their tuning.

4.6.3 Emissions

Due to its simple chemical composition and gaseous combustion, LPG mixes readily with the air in the engine and exhibits combustion properties generally superior to liquid fuels. It burns with nearly no particle emissions and hydrocarbon and carbon monoxide emission are lower. Through the combustion characteristics burning LPG also emits comparably less NO_X than gasoline and much less than diesel. The energy specific GHG emissions savings are relatively small compared with conventional diesel and gasoline (JEC, 2014b).[77] The TTW emissions are 17 g CO_2/km. The WTW emissions are 160 g CO_2/km as compared to 185 and 145 for gasoline and diesel respectively. The WTT emissions are 142 g CO_2 /km for LPG compared to 156 and 120 g CO_2/km for gasoline and diesel respectively.

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[77] The FQD annexes indicate considerable GHG savings, though.

Table 4-15: The range of WTT, TTW and WTW GHG emissions for LPG for 2010. Source: JEC (2014b) Appendix 1

Alternative fuel	**WTT g CO_2 /km**	**TTW g CO_2/km**	**WTW g CO_2 /km**
LPG	17	142	160
Conventional gasoline	29	156	185
Conventional diesel	25	120	145

While modern vehicles are already achieving lower emissions and performance values with the latest LPG systems (for dedicated LPG vehicles the TTW GHG-reduction is already at almost 16 %), research has indicated a further potential for LPG in increased efficiency and even cleaner exhaust, when using dedicated turbocharged direct injection engines.. The emission of particulate matter is negligible when compared with gasoline or diesel.

4.6.4 Energy efficiency

LPG vehicles generally have a WTW energy consumption that lies below gasoline and diesel, 241 MJ/100 km for LPG compared with 250 and 196 MJ/100 km for gasoline and diesel respectively.78

4.6.5 Maturity of technology

The most advanced technologies in the field of LPG have been developed in Europe. Leading companies have each independently mastered the technical challenges of liquid direct injection and provided solutions that are currently on the market. The European Union encompasses the largest common autogas market with individual countries like South Korea, Turkey and Japan following the lead closely. European innovation leaders like Landi Renzo and BRC (from Italy), and Prins and Vialle (from the Netherlands) export their systems to all parts of the world. These European companies, which are also the world leaders in the use of gaseous fuels for transport, provide LPG equipment to both carmakers for including them into their OEM models and to converters.

LPG has a high knock resistance allowing optimal combustion phasing and reduced needs for enrichment at high loads. The high LPG latent heat of vaporization provides a high cooling effect which enhances the volumetric efficiency when LPG is injected totally or partially in liquid state. However, research and further development is needed regarding variable LPG compositions in order to adapt the engine settings to avoid efficiency degradation. Moreover, LPG can be composed of alkenes such as butane or propene that depletes LPG knock resistance and can be responsible for carbon deposits (rubber) in the engine fuel circuit. Injecting LPG in liquid state in port fuel or in direct conditions is a complex task as pressure and temperatures need to be maintained over a narrow interval all along the fuel circuit: vapor locks need to be avoided. Along with direct injection goes the need for elimination of soot emissions.

4.6.6 Production cost of fuels

The development in the US propane price until 2012 is shown in Figure 4-16. The production cost of LPG depends highly on the pathway. As LPG is usually a co-product of larger processes, market prices and volumes produced in the respective process

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[78] The corresponding TTW figures are 216 MJ/100 km compared with 211 and 163 for gasoline and diesel, and WTT figures are 26 MJ/100 km for LPG compared with 39 and 33 MJ/100 km for gasoline and diesel respectively

decide, if LPG from that pathway is marketed. For instance several natural gas extraction projects reach break-even through the combined extraction and separate marketing of NGL due to the price divergence between oil based and natural gas-based products. As production processes have not yet been scaled to commercial levels in Europe, cost and production volumes estimates for LPG are difficult at this time (AEGPL, 2014).

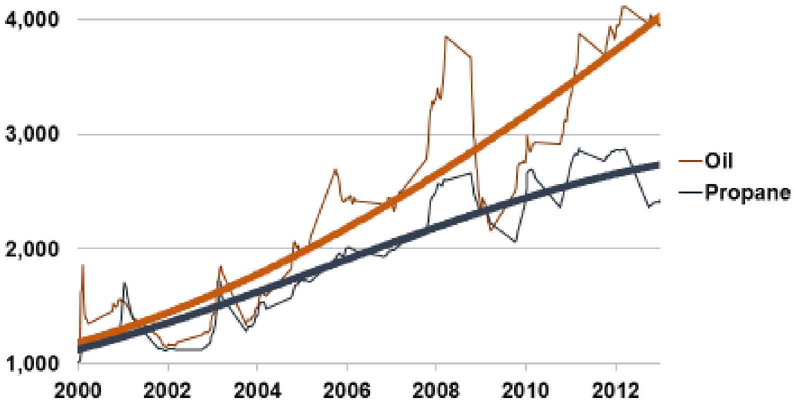

Figure 4-16: Price development of US propane.
Source: EIA

5 Market development for transport systems and infrastructure

5.1 Electricity

5.1.1 Maturity of technology

Due to current limits in battery capacity and driving range (currently 100-200 km for a small to medium-sized car), BEVs are today considered to be best suited to smaller cars and shorter trips, i.e. urban and suburban driving. Studies of driving patterns show that most drivers travel an average daily distance of around 50 km, which falls within the range of EV battery capacity. Given the long time in which the cars are stationary,79 range issues can also be further reduced if customers are encouraged to charge their vehicles regularly while they are parked at the office or at home, as not much power will be needed to fully recharge the battery. Catering for occasional longer range use is however important to foster a wider acceptance, and therefore fast charging and battery swap solutions need to be further developed and installed. The arrival of Tesla Model S in 2012 with a range of over 400 km has taken the market by surprise and has spurred a development of many long range BEV's in midsized and luxury models which will start to come on the market as of 2016. PHEV and REEVs are another possible solution to the problem, depending also on the frequency of the need for longer ranges, as well as other schemes like renting and sharing of longer range vehicles for occasional use.

The improvement of the range of EV's to 400 – 500 km will be a key success factor the coming years. However, it will also be important to develop short range, up to 150 km, low cost electric vehicles which will be very effective in city environments. These vehicles can also be light electric vehicles such as two wheelers (scooters and motors) or quadricycles.

The expansion of electrification of road transport to urban buses is a growing trend in Europe with electric buses expected to reach market maturity soon. The full battery electrification of heavy-duty vehicles and long-haul bus and coach fleets is not likely to be a realistic option in the near future. However, these technologies should be considered in a longer-term perspective as such fleets are very likely to become at least partially electrified by the use of plug-in hybrid technology.

Long hauls and HDV Although battery technology (BEVs and PHEVs) holds great promise for passenger cars and light vehicles, the outlook for long-haul heavy-duty vehicles is different. However, technologies for a continuous supply of electric energy during driving have the potential to complement greatly rail transport if it is not available, especially for heavy-duty freight trucks. Some implementations of such infrastructures could also be compatible with light vehicles, thus enabling a reduction of their battery size, with obvious advantages in terms of weight, energy consumption and cost, while providing further rationale for the deployment of such infrastructure. The recent developments in BEV and battery technologies show that the capacity and the range of new vehicles become longer. Concerning long haul passenger cars, models are coming on the market in the next few years. Today there are BEVs (e.g. Tesla) with ranges above 300 km. and other manufacturers are on way with similar long range BEVs (e.g. GM by 2016, Audi, Nissan and Ford have long range vehicles on the market in 2017). Even more important as indication that the strategy of OEM's is

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[79] Driving and parking patterns of European car drivers --- a mobility survey.
JRC report 2012.

changing, are the announcement of several car makers that they will introduce full electric luxury models with ranges from 450 to 600 km in next few years. Examples are Audi R8 e-tron in 2016 with a 450 km range, Audi Q6 SUV, Porsche 717 with a 500km range in 2019, Landrover, and Jaguar F-Pace SUV, 500 km range. Other carmakers like Mercedes and BMW are expected to follow. The move is seen as a reaction to the Tesla Model S.

Concerning HDV, it seems that the market is not developing many electric alternatives like PHEV and no BEV's. Hybrid HDV will however, offer the most interesting option to reduce fuel consumption at medium term. This needs probably to be incentivised by regulation to improve fuel efficiency. At long term but well before 2050, fully autonomous BEV long haul HDV is becoming a likely option. Autonomous vehicle technology for highway driving will probably be mature within the next decade. Applying this to long haul HDV ("between cities") offers the possibility for BEV vehicles, charging when needed during long routes as driving times are not as important for autonomous vehicles. Long haul stretches of 500 to 1000 km during the night at low speeds and charging at intervals may very well be the long term solution for emission free freight transport in 2050.

The technological maturity in relation to battery propelled maritime ferries is relatively low and additional feasibility cost studies have to be carried out, including the necessary supply infrastructure and overall implementability. There are different projects with battery driven smaller ships such as a ferry between two Danish islands.

Shore-side electricity for vessels at berth is also a mature technology to improve air quality at port. The implementation of shore-side electricity, however, has been rather challenging, partially due to the high power requirements associated with certain types of ships, e.g. cruise vessels, or peaks deriving from multiple ships berthed at ports at a certain moment. In addition taxation has been an issues as electricity produced on-board of vessels through auxiliary engines can be considerably cheaper than electricity obtained through the grid. Technical issues have mostly been resolved, although the costs of installing on-shore power supply on-board of vessels are still a limiting factor in the adoption of the technology.

There is also development in battery driven trains. The technological maturity is relatively low, even though the first battery driven locomotives emerged as early as in the 19th century80 and additional feasibility cost studies have to be carried out, including the necessary supply infrastructure and overall implementability.

Different interoperability platforms are carrying out important standardisation work with respect to both the recharging plugs and the data interchanges in order to promote open standards and harmonisation of data exchange and interfaces towards this end.

Below we will consider the market perspectives for the different transport modes, where we are further looking at the maturity of electricity with respect to these modes.

5.1.2 Data on vehicles/infrastructure

Over the past couple of years we have seen a rapid increase in the number of new BEV and PHEV entering both the European and world wide passenger car fleets (see Figure 5-1) as well as recharging infrastructure in EU, although sales are still only

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[80] Source: http://www.jhalpin.com/metuchen/tae/ehlai19.htm

limited compared to the total vehicle sales as shown below in Figure 5-2. Expectations are high for the future, though.

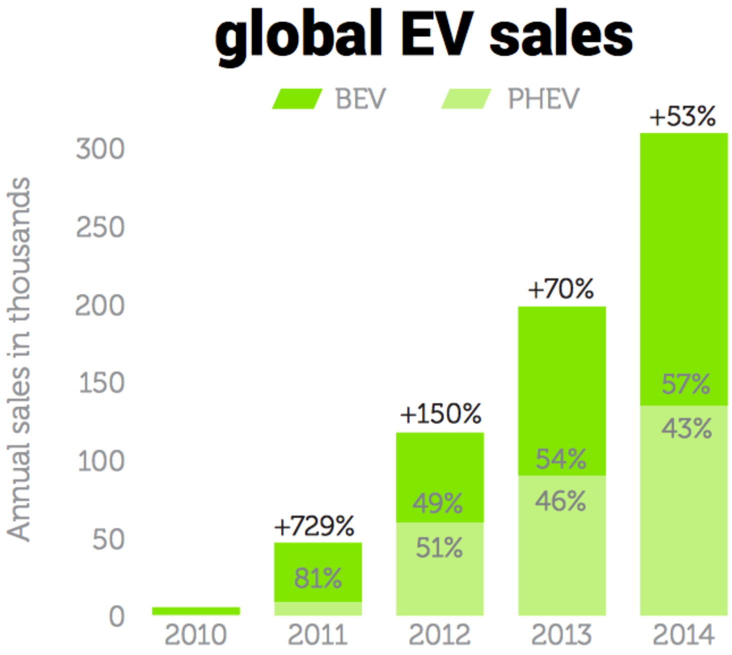

Figure 5-1: Development in global number of BEV, PHEV. Source IEA Electric Vehicle Initiative Global Outlook 2015.

The market share of electric cars out of new car sales in some countries are shown in Figure 5-2.

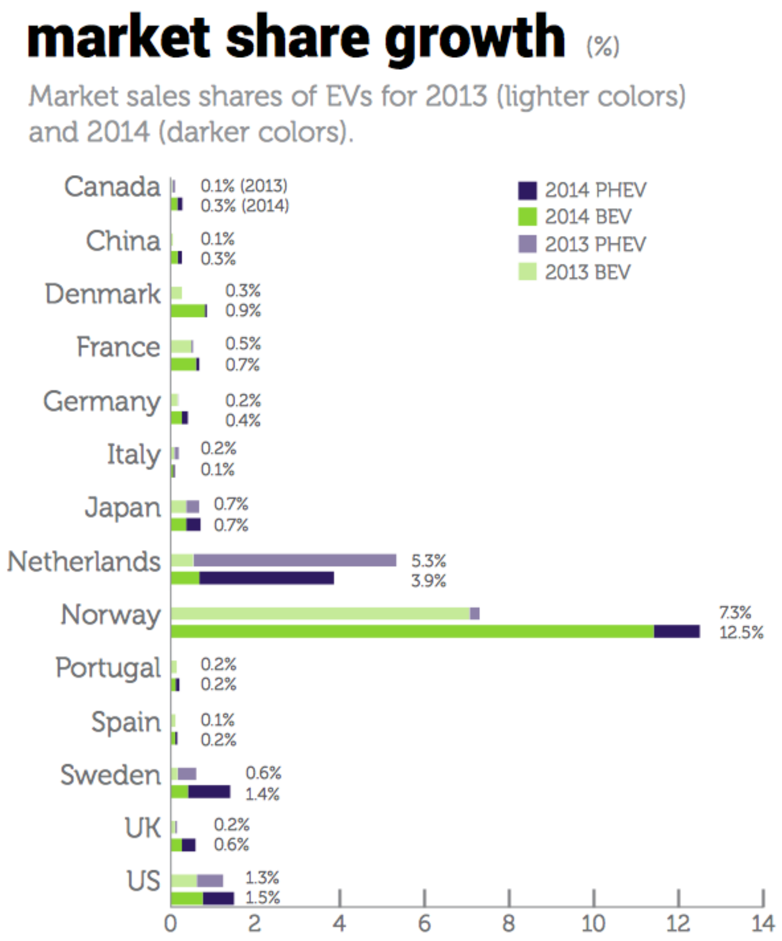

Figure 5-2: Market share (new sales) of electric passenger cars. Source: IEA Electric Vehicle Initiative Global Outlook 2015.

In 2014 almost 90,000 electric cars (M1 category) were sold in Europe of which 55,000 were BEV. The market share of EVs (PHEVs and BEVs) where below 1% in most countries, except for Norway and the Netherlands. While the high rate in Norway comes from BEV sales, the high rate in the Netherlands comes from PHEV sales. Statistical data on the PHEV and BEV fleets is collected by AVERE. The figures are presented in Table 5-2. With respect to the recharging infrastructure and although exact figures are difficult to obtain since there is a continuing installation of new charging points and charging stations. Relevant information is displayed in Table 5-3: overall it can be seen that the diffusion of charging points has started in some MS although it remains negligible in many.

Table 5-1 Total number of electric vehicles. Source: AVERE 2014 totals NA: Non Available

	PHEV		**BEV**	
	2014 sales	Total	2014 sales	Total
Austria	400	683	1155	2356
Belgium	830	1071	1163	1913
Bulgaria	0	70	0	50
Croatia	NA	NA	NA	NA
Cyprus	NA	NA	NA	NA
Czech Republic	42	51	29	120
Denmark	91	113	1514	2659
Estonia	2	2	315	453
Finland	257	392	181	231
France	1420	2889	10748	28023
Germany	4164	5958	8062	18461
Greece	NA	NA	NA	NA
Hungary	NA	NA	NA	NA
Ireland	37	38	216	402
Italy	284	533	1042	2372
Latvia	0	0	0	13
Lithuania	NA	NA	NA	NA
Luxemburg	NA	NA	NA	NA
Malta	NA	NA	NA	NA
Norway*	1699	2026	17938	31226
Poland	69	69	70	70
Portugal	126	150	165	390
Romania	NA	NA	NA	NA
Slovakia	NA	NA	NA	NA
Slovenia	0	70	0	253
Spain	409	601	971	2335
Sweden	1681	3456	445	1342
Switzerland	849	1887	1281	3684
The Netherlands	11862	35195	2927	6818
Turkey	NA	NA	NA	NA
United Kingdom	6629	8705	6479	11313
EU28+EFTA	30.851	63.959	54.701	114.484

** For Norway it is further expected that 3,000-4,500 second hand BEVs are imported.*

Table 5-2: Number of charging points in Europe. Source: European Electromobility Observatory and Eurelectric. Data are continuously being updated. Current figures are compiled November 2014. NA: None Available

	AC private dedicated socket (up to 22 kW)	***AC public and semi-public (up to 22 kW)***	***Fast charge DC public***
Austria	NA	3-400 (Type 2 Charging Stations	NA
Belgium	NA	NA	NA
Bulgaria	2	17	NA
Croatia	NA	NA	NA
Cyprus	NA	NA	NA
Czech Republic	~100	78	4
Denmark	NA	1.400 charging points	59 Chademo /31 CCS /~24 Tesla
Estonia	865	NA	164
Finland	NA	50	10
France	NA	8.600	NA
Germany	More than 650	4.800	100 CCS
Greece	NA	NA	NA
Hungary	NA	NA	NA
Ireland	860	810	64
Italy	NA	NA	NA
Latvia	NA	13	NA
Lithuania	NA	NA	NA
Luxemburg	NA	NA	NA
Malta	50	NA	NA
Norway	NA	1529	4804
Poland	NA	NA	NA
Portugal	19	415	11
Romania	NA	NA	NA
Slovakia	NA	NA	NA
Slovenia	17	101	1
Spain	NA	752	NA
Sweden	NA	743	AC 44 kW: 23; DC >22 kW: 308
Switzerland	NA	800	29 (Tesla), 45 CCS /45 Chademo
The Netherlands	18000	5770	106
Turkey	NA	NA	NA
United Kingdom	NA	NA	NA

The figures about number of charging points is quite uncertain since Member States count differently. AVERE has collected what they consider the most accurate figures for Belgium, France, Germany, The Netherlands, Norway and the UK as shown in Figure 5-3.

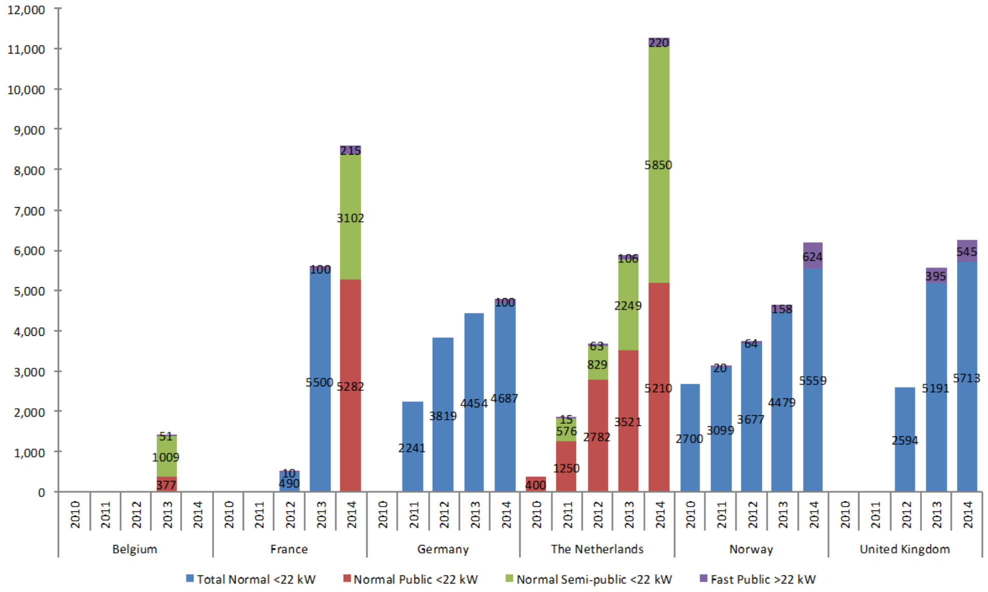

Figure 5-3: Charging points in selected countries. Source: AVERE

A number of EU demonstration initiatives have been launched to promote electric vehicles as part of the European Green Vehicles Initiative. A short description of some of these are contained in 0.

Electric buses demonstrations will be done in eight European cities (Barcelona, Bonn, Cagliari, Glasgow, London, Munster, Plzen and Stockholm).

5.1.3 **Cost of vehicles and infrastructure**

The cost of electric vehicles is mainly affected by the battery system cost. EV battery costs are projected to go down from € 1,000 in 2010 to € 200 per kWh in 2020. [81] On top of this, due to light weighting of cars and better performance of electric vehicles less kWh per km is needed. Bosch has stated for example that again comparing 2010 and 2020, for the same distance 45% less kWh per km will be required. The USA EV Everywhere programmer has similar projections. The cost of EV technology is being reduced at a much faster rate than projected. Similarly the range of EV's is improving with several 300 km+ range models coming on the market in 2016 and 2017 at prices around $ 35.000 (GM Bolt, Tesla model 3, Nissan LEAF). Even more important as indication that the strategy of OEM's is changing iare the announcement of several car makers that they will introduce full electric luxury models with ranges from 450 to 600 km in next few years. Examples are Audi R8 e-tron in 2016 with a 450 km range, Audi Q6 SUV, Porsche 717 with a 500km range in 2019, Landrover, and Jaguar F-Pace SUV, 500 km range. Other carmakers like Mercedes and BMW are expected to follow.

BEV's are already cost competitive in some situations and circumstances. AVERE projects that within 5 to 10 years BEV's will be price compatible with ICE vehicles in most situations and will be the car of choice. However, this may also depend on how the taxing of BEV and ICE vehicles is set up in the future.

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[81] Christophe Pillot, Avicenne Energy (2012). *The worldwide battery market 2011-2025.* Presentation at the Batteries 2012 conference, Nice, October 2012.

By 2020, the cost of BEV components could decline by 80% from 2010. In addition to this, battery weight will reduce and the overall efficiency of BEV's will increase. All these changes together result in a situation in 2020 compared to 2010 whereby for a 200 km range, 45% less battery kWh is require and the cost of this smaller battery is only 10-15% of that of the battery needed for a 200 km range in 2010 (Bosch, 2013).

For the users of vehicles, the total cost of ownership (TCO) are typically calculated to evaluate and compare the situation for the user of the electric vehicles. These calculations include the actual (national) taxes and duties. Hence, changes in taxing regimes or sizes also influence the TCO values.

We already today see examples of TCO, where, BEVs and PHEV's are cost-competitive with ICEs in relevant segments (e.g. in some corporate or municipal fleets). BEVs have a higher purchase price than ICEs (mainly due to high battery cost) but a lower fuel cost (due to greater efficiency and no use of oil) and a lower maintenance cost (e.g. due to fewer moving parts, absence of catalyst and other emission control systems).

According to FCH-JU (2012) the fuel economy of ICEs is expected to improve by an average of 30% by 202, although this will be at a cost estimated by the industry to be around 3,000 to 5,000 Euro. Costs also increase due to full hybridization and further measures such as the use of lighter weight materials. However, as the recent ICCT report on real world fuel use have shown, the difference between the theoretical energy consumption and the real world consumption has increased in the past years. It is not possible to say to which extent this will also happen in the future.

5.1.4 Perspectives for market development

The infrastructure for charging electric vehicles is already in place i.e. the distribution grid. The infrastructure already available in domestic settings is being complemented by charging equipment in parking lots or office buildings using different charging methods across Europe. Eurelectric has recommended three types of charging methods: "normal power" (<=3.7 kW), "medium power" (3.7 – 22kW), "high power" (>22 kW). The charging method of electric vehicles will depend on where the customers want to charge their electric vehicles. The standard for fast charging is now 50 kW (DC) and is expected to increase with the increasing battery sizes of the FEV's. For comparison, the proprietary Tesla superchargers are already up to 130 kW.

The bulk of the charging can be done with off-peak charging with lower power, which is consistent with a great proportion of users' needs as a large majority of BEVs is charged at home or at the office. Further AC-charging modes with power of up to 22 kW with smart charging could be introduced in certain public spaces. A high-power charging option has to be offered, however, as a back-up to allow for occasional long-distance trips in line with customers' demands and this normally can take place at peak times. Throughout Europe, fast chargers are being installed at or along highways. Examples of TEN-T supported projects are Electric (Netherlands, Germany, Denmark, Sweden, 155 fast chargers), in and around Austria (115 fast chargers), Rapid Charge Network in the UK (74 fast chargers) and Corridor (France, 200 fast chargers). In the Netherlands the 200 fast charging station network *Fastned*, which is privately financed is currently implemented at a cost of 40 million euros including a solar PV covered roof and multiple fast chargers at each stations. The cost of a 50 kW fast charger unit is now around 10k€.

Owing to limits in battery capacity and driving range (currently 100-200 km for a small to medium sized car) and a current recharging time of several hours in private areas, BEVs are ideally suited for urban and suburban driving. However, faster charging solutions are now available on the market for both private car owners and larger car fleet owners. Typically, a wall mounted charging solution that can fully charge a BEV in 1.5-2.5 hours, costs approximately EUR 500 to 1,500.[82] Charging during the day means that the overall range of the BEV can be increased significantly. In addition to that, in recent years, manufacturers like Tesla, GM/Opel, Ford[83] and BMW have launched new car models with extended ranges (from 250 to 600 km), either by larger car batteries or by small range extenders (serial hybrids with < 10 litres fuel tank), that are not directly connected to the driveline of the vehicles.

WECVs[84] uses an electromagnetic field to transfer energy between two objects. This is usually done with a charging station. Energy is sent through an inductive coupling to an electrical device, which can then use that energy to charge batteries or run the vehicle. In theory, the range of a WECV may be infinite due to the remote location of the energy source being continuously and wirelessly transferred to the vehicle's propulsion system. In practice, a limited number of charging points - at or below the road surface - will require that some battery capacity is installed in the cars[85].

Although battery technology (BEVs and PHEVs) appears usable for passenger cars and light vehicles, the outlook for long-haul heavy duty vehicles is different.Technologies for a continuous supply of electric energy during driving have the potential to complement rail transport if it is not available, especially for heavy-duty freight trucks. Both overhead contact line[86] (Scania, 2012), and WECV versions (ground based inductive and conductive) of such technologies exist as prototypes or early commercial versions from several suppliers worldwide[87] (ERTRAC, 2014). Electric city buses or plug-in hybrid city buses are solutions already available at the market and are for example currently being deployed at high numbers in Chinese cities (thousands per city). For these buses fast chargers with power rating from 200 to 400 kW are being developed. Electrification of heavy duty vehicles is also already being piloted for specific applications like mining, harbour and off road.

Electrically propelled battery ferries are about to enter regular service in Scandinavia (in 2015). The recharging time in the harbours can be as low as 10 minutes depending on the vessel size and powering requirements. The service crossing distance should though be relatively limited (short haul inland waterway transport) (Clean Technica, 2013).

The technological maturity is relatively low and additional feasibility cost studies have to be carried out, including the necessary supply infrastructure and overall implementability.

Electrification in shipping is an emerging option for short shipping networks and includes four tracks: (a) hybridization of conventional systems with batteries, (b) electrification of power systems, (c) development of smart power management systems to maximize benefit in exploiting the battery advantages, and (d) on-shore power infrastructure.

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[82] Source: http://www.eon.com/en.html
[83] http://corporate.ford.com/microsites/sustainability-report-2013-14/environment-products-plan-migration-phev.html
[84] Wireless Electric Vehicle Charging
[85] Source: www.ecofriend.com
[86] Source: http://newsroom.scania.com/en-group/2012/07/04/electric-truck-for-alternative-ore-transportation/
[87] Source: http://www.ertrac.org/uploads/documentsearch/id32/2014-03-12_Roadmap_Energy_Carriers_for_Powertrains.pdf

Development is performed on independently powered electric trains running on battery power over non-electrified lines, before charging at terminal stations, or using their batteries to run over diesel lines in otherwise electrified parts of the railway. As part of industry studies into the feasibility of using electric trains on parts of the network that have not been electrified, prototype battery-powered trains are being developed[88] (Railway strategies, 2013).

The technological maturity is relatively low, even though the first battery driven locomotives emerged as early as in the 19th century[89] and additional feasibility cost studies have to be carried out, including the necessary supply infrastructure and overall implementability.

Airbus has made small experimental electric airplanes for long-term potential studies of electricity as alternative major on-board energy source for future short haul flight services with up to 90 passengers[90] (CNET, 2014).

Electromagnetic aircraft launch systems are under development to launch carrier-based aircrafts from an aircraft catapult using a linear motor drive instead of the conventional steam piston drive. The main advantage is that this system allows for a more graded acceleration, inducing less stress on the aircraft's airframe and the passengers inside.

The technological maturity is low and feasibility cost studies have to be carried out, including the necessary supply infrastructure and overall implementation.

In addition there are various initiatives to use electricity for airport activities on the ground. A long-established procedure is electricity supply to airplanes at the terminal gate, while more recent initiatives also aim to electrify taxi operations. Whilst not meeting the energy requirements of the actual flight, such initiatives can reduce fuel consumption and noise, improve air quality and reduce the impact on the climate.

5.2 Fuel cell electric vehicles and hydrogen vehicles

Fuel Cell Electric Vehicles (FCEVs) as well as BEVs use electric drivetrains. However, in FCEVs the electricity is not stored in a battery - it is produced on board by a fuel cell using oxygen from the air and hydrogen stored in a tank.

In essence, a fuel cell is similar to a battery in that it generates electricity from an electrochemical reaction (different from combustion). However, a battery holds a closed store of energy within it, and once depleted, it must be discarded or recharged using an external supply. A fuel cell must also be supplied with new hydrogen fuel once depleted, but a full tank allows running a significantly longer distance than a battery. It is similar to an ICE in that it oxidises fuel to create energy, but rather than using combustion, a fuel cell oxidises hydrogen electrochemically, with water vapour as the only exhaust. FCEVs are inherently more efficient than ICE cars with TTW efficiency lying at over 40% (state of art 2015). It is also similar to an ICE in that it can be refuelled in three to five minutes for a driving range of 500-600 km. Also, the power and the driving range of the car can be set independently since the first depends on the size of the fuel cell and the electrical engine, and the second depends on the size of the tank[91]. Hybrid architecture combines a fuel cell (from 0 to 100%)

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[88] Source: http://www.railwaystrategies.co.uk/article-page.php?contentid=18668&issueid=521
[89] Source: http://www.jhalpin.com/metuchen/tae/ehlai19.htm
[90] Source: http://www.cnet.com/news/airbus-shows-e-fan-its-electric-plane-due-in-2017/
[91] Adapted from "Fuel Cell Electric Vehicles: The Road Ahead" published by Fuel Cell Today in 2012, with use of own NEW-IG data.

and a battery (from 100% to 0 %). In particular a Range-Extender approach (RE-FC) allows to add a small fuel cell (5 kW) in an existing BEV, with a 1 or 2 Kg Hydrogen tank. This range extender allows to double the range of BEV without needs of a full power fuel cell.

In addition, hydrogen fuel cells also have a potential as on-board auxiliary power units (APUs) for road and non-road applications like shipping or aviation, among others.

5.2.1 Maturity of technology

Passenger cars The first FCEV passenger vehicle was developed in 1997. Since then, significant technological advancements have been achieved. The technology has been introduced in both public transport and in light duty transport vehicles. Car manufacturers such as Daimler and Honda introduced small demonstration fleets in 2005 and 2006. In 2009, seven of the world's largest automakers, Daimler, Ford, General Motors, Honda, Hyundai-Kia, Renault-Nissan and Toyota addressed the oil and energy sector requesting a hydrogen infrastructure. The reason was the intent to commercialise a significant number of fuel cell vehicles from 2015[92] (FuelCelltoday, 2013). The plans for the automakers are that Hyundai, Honda and Toyota have a FCEV commercially introduced on the European market in 2015. Other automakers such as Daimler, and Nissan follow one to two years later.

The technology as such is mature, safe and ready for deployment in road transport. The commercialisation process has begun within some specific market segments; for example passenger cars, buses, materials-handling vehicles and passenger cars. There are already more than 500 electric vehicles powered by hydrogen operating in Europe, mainly in Germany, Scandinavia, the UK, the Netherlands and in France. The operation of fleets of fuel cell buses for public transport has already started in London, Hamburg, Cologne, Milan, Oslo and other cities.

However, the levels of cost competitiveness and performance required for large-scale deployment in road transport have not yet been achieved, neither for the vehicles nor for the refuelling stations. Furthermore, important framework conditions required to foster widespread commercialisation of these technologies, such as the infrastructure to produce, distribute and store hydrogen in a sustainable manner, end-user confidence and the availability of appropriate regulations, codes and standards have not yet been fully met.

Two things are needed for the market introduction of FCEV: the cars themselves and hydrogen refuelling stations to support them. In any market, a minimum number of each is necessary to support demand for the other[93] (FuelCelltoday, 2013).

Initial deployments are likely to focus on government fleets, other return-to-base fleet operations and the high-end consumer car market in areas with an appropriate level of infrastructure. Following early market introduction, widespread consumer acceptance and adoption will be gradually, accelerating as infrastructure density increases and the cost of production of the vehicles and the hydrogen fuel decreases. Ultimately, take-up will depend on the advantages and costs of FCEV when judged against alternatives[94] (FuelCelltoday, 2013).

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[92] http://www.fuelcelltoday.com/media/1711108/fuel_cell_electric_vehicles_-_the_road_ahead_v3.pdf
[93] http://www.fuelcelltoday.com/media/1711108/fuel_cell_electric_vehicles_-_the_road_ahead_v3.pdf
[94] http://www.fuelcelltoday.com/media/1711108/fuel_cell_electric_vehicles_-_the_road_ahead_v3.pdf

Projects funded by the Fuel Cell and Hydrogen Joint Undertaking (FCH-JU), a partnership between the European Commission, the industry and the research world, over the period 2008-2013 have produced research results towards technological advancement and fostering the development and deployment of new technologies and concepts. The FCH-JU has been extended to an additional program period from 2014-2024. A number of cars, buses, refuelling stations and material handling vehicles (MHVs) have been deployed through FCH JU's framework.

The current approach for on-board storage focuses on high-pressure hydrogen storage, but alternative storage technologies available after 2020 may reduce storage pressure and volume.

There are also projects considering the use of fuel cells on-board ship, for example the FellowSHIP project. In the FellowSHIP project, a 330 kW fuel cell was successfully installed on board the offshore supply vessel Viking Lady, and demonstrated smooth operation for more than 7000 hours. This is the first fuel cell unit to operate on a merchant ship, and proves that fuel cells can be adapted for stable, high efficiency, low-emission on-board operations.

Also, DNV GL was the first class society to develop rules for fuel cells on-board ships. Finally, the PaXell project considers the installation of fuel-cell clusters on-board cruise vessels. A general description of the possibilities are outlined in DNV (2012).

5.2.2 Data on vehicles/infrastructure

The European Electromobility Observatory collects information about the number of BEVs, PHEVs and FCEVs in Europe; the figures are not complete and information is missing for several countries. According to the counts, 167 FCEVs are registered in European countries, although other older sources (e.g. the *Powertrains for Europe* report from 2010) claim figures with several hundreds of FCEV. These higher figures have not been verified beyond the statements, though.

The infrastructure for hydrogen as fuel is in an early build-up phase, which constitutes a key obstacle to market development. Only around 200 hydrogen refuelling stations (HRS) are found worldwide out of which approximately 100 is in Europe (NEW-IG). Thus, the necessary HRS infrastructure needs to be established. In the first stages of the market introduction of FCEVs, utilisation of the HRS will be low, leading to a negative business case (similar to public charging stations for BEVs). In a later state, when closer to full utilisation is achieved, the business case can be positive. NEW-IG, the industry grouping that is part of the FCH-JU, estimates that the investments needed for hydrogen infrastructure are around 5% of the overall cost of fuel cell electric vehicles.

In the case of a reformer being part of the fuel cell system, it is possible to fuel vehicles with hydrocarbons like methane, diesel or kerosene. The advantage would be that the necessary infrastructure is either already existing or easier to build up (e.g. LNG as fuel for ships). However, reformer FC systems are much more complex compared to those fuelled with pure hydrogen and the maturity is significantly lower.

FCEVs have been deployed in a range of demonstration projects throughout the world. The technological challenges identified as critical for the successful implementation of fuel cells in vehicles at the turn of the millennium have all been resolved. This includes start-up and operation in temperatures down to -30°C, which has been demonstrated. The driving range of today's FCEVs is now 400-600 km; and refuelling times have been reduced to 3-4 minutes for passenger cars and ~10 minutes for buses. A range of developments over the last 20 years mean that FCEVs are now very reliable, with availability of 98% achieved. In terms of performance, these passenger vehicles are ready for market introduction. However, to become fully commercially viable, the costs of FCEVs still need to be reduced and lifetimes increased. According to NEW-IG the lifetime has already increased from a few hundred operating hours to several thousand operating hours.

The majority of large car manufacturers throughout the world are working on the development and market introduction of fuel cell passenger cars, while multiple bus manufacturers are developing and deploying fuel cell electric buses (FCEBs). Additionally, some smaller manufacturers have developed two-wheel and four-wheel FCEVs and demonstrated their maturity in different demonstration projects. At the same time, range-extender electrical FC-vehicles (RE-FCEV) are being developed and tested for some segments such as light commercial vehicles and all captive fleet vehicles, including companies fleet and professional vehicles, taxis, rental vehicle, In e.g. France this segment represents up to 50% of the total car market. A range extender solution could be deployed on BEV in order to extend vehicle range.

Owing to significant decrease of fuel cells' cost and increased lifetime, some car manufacturers have already announced the market introduction of FCEVs for 2015 and the following years. In particular, Toyota Motor Corp. has started to sell the Mirai model in Japan in December 2014 at a cost of $57,400. Some such vehicles are expected to be sold in Europe in 2015 while Hyundai is already offering its iX35 FCEV for either lease or sale in the UK and Scandinavia since late 2014.

A Europe-wide network of hydrogen refuelling stations (HRS) has yet to be established, but the numbers have grown significantly, and are now approaching 100 stations according to NEW-IG. At the same time, the cost of HRS has fallen, while the reliability and lifetime of HRS technology have increased. HRS have been demonstrated at different sizes from stations that supply small demonstration fleets, to HRS that are capable of supplying highly frequented public locations. The 700 bar refuelling technology is established as the predominant refuelling pressure level for passenger cars, while 350 bar is used for buses, forklifts and RE-FCEVs for some market segments like light commercial vehicles. With a standardized refuelling interface, the inter-operability of emerging HRS networks is already advanced. The targeted refuelling time has been reached by pre-cooling the fuel and applying infrared communication between the vehicle and the filling station meeting the SAE J2601 standard.

The major remaining technological/standardization issue for refuelling is the metering accuracy of dispensers. Current technology for metering hydrogen can achieve at best +/- 3% accuracy; higher accuracies will be needed for public billing purposes, (for example +/- 1% is required for dispensing natural gas). Additionally, hydrogen compressors are still a barrier; being both too expensive and not reliable enough for commercialisation purposes. The maximum impurity levels allowable by standards should be revised to take account of the trade-off between the cost of cleaning the hydrogen produced at the HRS and the associated lifetime expectancy for the PEM fuel cell stack on board the FCEV.

5.2.3 Cost of vehicles and infrastructure.

The EU power train study[95] has in 2010 looked into the costs of FCEVs. FCEVs are expected to have an initial higher purchase price than ICEs (battery and fuel cell

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[95] A portfolio of power-trains for Europe: a fact-based analysis.
http://ec.europa.eu/research/fch/pdf/a_portfolio_of_power_trains_for_europe_a_fact_based__analysis.pdf

related) and lower fuel cost (due to greater efficiency and no use of oil) and a lower maintenance cost (fewer rotating parts). The cost of fuel cell systems is expected to decrease by 90% by 2020 compared to 2010, due to economies of scale and incremental improvements in technology. Around 30% of technology improvements in BEVs and PHEVs also apply to FCEVs and vice versa, as they share a number of components such as electric drivetrains and other power-electronics. According to NEW-IG costs have fallen from more than a million Euros per fuel cell powered passenger car at the beginning of the millennium to less than one hundred thousand euros in 2015. The cost of hydrogen out of the HRS also reduces by 70% by 2025 compared to 2010 due to higher utilisation of the refuelling infrastructure and economies of scale.

The TCOs of FCEV and ICE are expected to converge after 2025 – or earlier, with tax exemptions and/or incentives during the ramp-up phase (according to the Powertrain study).

The cost of hydrogen refuelling station is depending on the size and performance of the station and is in the range of 100,000 Euro to 2 Million Euro. The costs of hydrogen retail and distribution are estimated at 1,000-2,000 Euro per vehicle (over the lifetime), including distribution from the production site to the retail station, as well as operational and capital costs for the retail station itself. The average annual investment in distribution infrastructure in Europe is estimated to be around 2-3 billion Euro compares to that for other industries, such as oil and gas, and infrastructure along roads, which each amount to 50-60 billion Euro[96]. It is also significantly less than additional investments required to decarbonize power (1.3 trillion Euro over 40 years)[97].

The current cost of the vehicles depend on the country and model and could oscillate between € 55,000 and 80,000. The sales of the Toyota Mirai (Japanese for "future") began on 15 December 2014. The Japanese government plans to support its commercialization with a subsidy of US$19,600). Retail sales in the U.S. are scheduled to start by mid-2015 at a price of US$57,500 before any government incentives, The market release in Europe is expected to start in September 2015, in UK, Germany and Denmark. The only EU manufacturer Diamler is expected to propose a model in 2017, but the price is not yet estimated. Hyundai has put their ix35FCEV model on the Dutch, Norwegian and Danish market at a price of 66,000 Euro.

5.2.4 Perspectives for market development

Major global manufacturers are looking into developing FCEVs as part of their product portfolio. Worth noting are recent strategic cooperation contracts between leaders such as BMW and Toyota (2012), GM and Honda (2013), or Daimler, Ford and Nissan. 2013). The automotive industry has invested several billion Euros in FCEVs over the last 20 years. The industry further estimates the industry financial effort for FCEV development in range of at least 500 million Euro per year in total seen over a period of 5-10 years.

Various initiatives are being developed across Europe to bring FCEVs and the related infrastructure to customers as a competitive option. In the transport sector, the applications of fuel cell systems in fuel cell electric cars and buses is the most advanced one. The technology is mature for series production and all important technical issues, including hydrogen storage and freeze start-up have been solved.

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[96] Global Insight
[97] FCH-JU (2012)

Two car manufacturers have already FCEVs on sale and lease for normal customers. Other car manufacturers have announced market introduction in the next years. The necessary build-up of HRS has already been started, notably in Germany, where the H2MobilityDeutschland GmbH has been founded, a company, which will build up 400 HRS in Germany until 2023. In other European member states similar initiatives are in place. Some examples are outlined in 0.

Other transport modes

- An advanced level of technology readiness has been achieved for material handling vehicles. These are close to market introduction in Europe; although in other markets up to 4,000 vehicles are reported to be in operation, often with public financial support.
- Applications of FCH technologies in non-road propulsion and Auxiliary Power Units (APUs) applications are less mature than for road propulsion. Functionality, performance and operational lifetime need (ignoring material handling equipment, which is commercially available in the US and being competitive with conventional battery powered units) to be improved and costs reduced. Relatively few FCH systems (besides in passenger cars and buses) have reached a formal demonstration stage and market introduction by OEMs has typically been indicated from 2018-2020 onwards.
- In the **COMMERCIAL AVIATION SECTOR**, FCH APU technologies are a pathway towards meeting increased on-board power demands from more electric aircraft architectures (rather than diverting power from main engines in flight) and can be used for on-board loads on the ground and runway taxiing. Fuel cell systems are being evaluated for replacing conventional tailcone APUs and/or as multi-functional systems providing ~200kW electric, plus thermal, water generation and oxygen depleted air outputs for future commercial aircraft implementation. They are also being evaluated (<20kW) for replacement of mechanical ram air turbine systems. Flight testing of representative systems is anticipated from 2016 onwards. There are no formal FCH system standards and requirements across the aviation sector for APU as yet and the critical issues that need to be addressed are weight reduction along with high levels of reliability and availability. On-board hydrogen storage and replenishment also needs to be addressed. FCH technologies are also being evaluated for unmanned air vehicles, where small scale (<1kW) FCH systems have been used in hybridised and range extender applications for military and civil applications.
- In the **MARITIME SECTOR**, there is long-standing experience of FCH systems used in submarine applications. Hydrogen can be stored on board vessels in metal hydride storage, as compressed gaseous hydrogen or in liquefied form. Some applications combine hydrogen-powered fuel cells with batteries. Storage of the fuel, however, is complex and requires either high pressure, temperatures close to the absolute zero or heavy hydide storage systems. Classification rules for transporting hydrogen exist but for using hydrogen as marine bunker fuel do not exist yet. Elsewhere, FCH based APUs are being evaluated for providing power (250kW upwards) to cover in-port operations and 'hotel' loads for ferry and larger vessels and thereby reduce CO_2 and other emissions from main engines operating on heavy fuel oil and marine diesel. FCH systems have also been trialled for propulsion of smaller passenger and tourist/leisure vessels as well as for day-trip vessels in inland navigation. There are no formal standards and requirements across the maritime or inland navigation sectors yet, and the critical issues that need to be addressed for APUs are reliable performance, lifetime and cost – with criteria largely similar for mid-sized stationary power generation, except for weight and packaging/space issues.

- In the **RAIL SECTOR,** FCH systems have already been trialled for niche mining and shunting locomotive applications and are being considered as (200kW+) APUs for diesel powered rail units to cover 'hotel' loads and eliminate main engine idling while in stations for emissions reduction purposes. The critical issues to be addressed are reliable performance, lifetime and cost – again with criteria similar to mid-sized stationary power generation, except for weight and packaging/space issues. Hydrogen storage systems are also an issue where hydrogen is being considered as an internal fuel system.

5.3 Biofuels

5.3.1 Maturity of technology

Road transport Biofuels could technically substitute oil derived fuels in all transport modes, with existing power train technologies and existing re-fuelling infrastructures. Blending biofuels with fossil fuels not exceeding the limits specified by the Fuel Quality Directive (FQD) (10% ethanol/22% ETBE within the oxygen content limit of 3.7%, 7% biodiesel) has the advantage that neither new engines nor new infrastructure is necessary. Increasing ethanol and biodiesel contents in the blends will likely require adaptations to engines and exhaust after treatment designs. Higher blends also require some adaptations to the existing infrastructure and a dedicated distribution system. Advanced fuels (2nd and 3rd generation) are fully compatible with the current vehicles technologies and infrastructures.

The specifications for bioethanol (100%) - EN 15376 - and for bioethanol (85%) -prEN 15293- already exist as well as the specification for biodiesel (100%) -EN14214- A fuel specification for biodiesel (30%) for use by captive fleets of dedicated vehicles and biodiesel (10%) are in process of adoption by the European Committee for Standardization.

In 2020, about 95% of the passenger cars and vans will be compatible with E10, and all diesel vehicles are compatible with B7 since model year 2000. (TNO, 2013)

For aviation, advanced biofuels are considered the only low-GHG short to medium term option for substituting fossil kerosene. The development of these fuels can bring substantial GHG reduction, in complement of all other improvements such as aircraft aerodynamics, weight, propulsion system, operation (e.g. green taxiing, and optimised routes) The compatibility of bio-kerosene from FT process (blending up to 50%) and DSHC pathway (blending up to 10%) with today's aircraft engines has been approved for operation in commercial flights (ASTM D/7566), and since then 21 airlines worldwide (10 of them European) carried out over 1600 commercial flights powered with various biofuel blends. Note that aviation can only accept drop-in fuels, which require no (prohibitively costly) adaptation of existing aircraft or airport fuel supply infrastructure.

5.3.2 Data on vehicles/infrastructure

E10 petrol is only available in France, Germany and Finland.[98]

The number of high-blend (e.g. E85) biofuels vehicles running in the EU is approximately 250,000 and the number of refuelling stations is nearly 4,500. Vehicles and infrastructures are not available on a significant scale except for E85 in Sweden, France, Germany and the Netherlands.

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[98] E10 is the common name for "Ethanol equivalent" since also ETBE is used as blend in E10

The approximate numbers of E85 vehicles and pumps in these Member States are the following (2012 figures):

Sweden: 1,700 fuelling stations/225.000 vehicles; Germany: 343 filling stations and 24,000 vehicles; France (SNPAA, 2015): 600 filling stations/30,000 vehicles; Netherlands: 33 filling stations/10,000 vehicles (Exergia, 2012).

The number of vehicles running with other blends, such as biodiesel-100, biodiesel 30, ED95 (95% ethanol, 5% cetane improver) is limited. These fuels are mainly used in dedicated public fleets, e.g. the Stockholm buses by Scania.

5.3.3 Cost of vehicles and infrastructure

According to stakeholders[99], the suggested cost of adaptation of a conventional pump station into a biofuel station could range between 5,000 - 20,000 Euro, while for a new pump the cost could range between 15,000-30,000 Euro, storage enlargement not included.

The cost of the biofuel vehicles is not significantly different from gasoline or diesel vehicles. Except flexi-fuel cars running with E85, vehicles running with high blend biofuels are conventional vehicles with minor engine adaptations.

Also, the transport and distribution costs vary between different fuels. This has been assessed by IEA (2013) for two different scenarios (a scenario where only today's technology is implemented and a scenario where all foreseen developments in the various technologies have taken place). Table 5-3 shows the results of the calculations.[100] The table includes biofuels, CNG/methane, hydrogen and electricity. The table reflects partly the maturity of the fuels, where the fuels that are already present in the market do not foresee large reductions in transport and distribution costs, whereas less mature fuels will benefit from technology developments scale efficiencies. Moreover, the fuels that to a large extent are able to use current infrastructure (ethanol, ETBE, biodiesel, drop-in fuels) have lower costs almost similar to costs of conventional fuels. Only minor additional investments in infrastructure are needed, increasing costs slightly.[101] Natural gas, hydrogen and electricity still require investments in supply infrastructure and will thus lead to higher transport and distribution costs, as also shown in the table.

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[99] Exergia (2011) *Assessment of the implementation of a European alternative fuels strategy and possible supporting proposals*. http://ec.europa.eu/transport/themes/urban/studies/doc/2012-08-cts-implementation-study.pdf

[100] In the report, different oil prices are used. Here the 60 USD/bbl is shown. There are some variations in the relative costs depending on the chosen oil price, since it influences transport costs, and to some extent the storage costs as well.

[101] This is assessed by stakeholders as explained in Exergia (2012).

Table 5-3: Cost of transport, distribution and refuelling infrastructure for energy pathways (USD 60/bbl)[102]*. Source: IEA, 2013.*

Energy carrier	Amortised costs (USD_{2010}/GJ_{LHV})					
	Current Technology Scenario			Mature Technology Scenario		
	Total costs	Transport costs	Storage and refuelling costs	Total costs	Transport costs	Storage and refuelling costs
CTL, BTL, GTL	3.266	3.198	0.068	3.260	3.198	0.061
Ethanol	3.522	3.412	0.110	3.511	3.412	0.099
Biodiesel	1.719	1.641	0.079	1.711	1.641	0.071
Natural gas, bio-SNG	7.675	3.152	4.523	2.687	1.367	1.320
Centralised H_2	86.457	70.898	15.559	13.820	4.191	9.629
Electricity	13.168	2.173	10.996	8.440	1.965	6.475

5.3.4 Perspectives for market development

Biofuels can be used in all transport sectors, low blend biofuels will be used in road transport, biodiesel can also play a significant role in rail in areas where electrification has not yet been implemented.

For the commercial aviation sector, three production pathways have already been approved (Fisher-Tropsch-fuels (FT), Hydrogenated Ester and Fatty Acids (HEFA) and Synthezised Iso-Parafins from Hydroprocessed Fermented Sugars (SIP)), and several more are nearing approval. The main obstacle is the availability of biofuels at competitive prices.

Aviation A set of scenarios for jet fuel use has found a potential demand of 375 Mt per year in 2010 up to 575 Mt in 2050 globally. Assuming that biofuels are used as blends in conventional jet fuels up to 10% leads to an annual demand in 2050 of 57.5 Mt. Winchester et al (2013)[103] has in a modelling exercise projected the 2020 fuel jet price to be $3.41 per gallon (corresponding to 0.73 €/liter). They have used this to estimate what implicit subsidy is needed to convert to biofuel. In their estimated this subsidy could go up to 0.58 €/liter jet fuel, but the figure can be reduced if e.g. there is sufficient rotation crop oil to meet the aviation goal.

Greening the future of aviation, fulfilling the industry’s pledge to halve its carbon emissions by 2050, will be hence pivotal to this endeavour. However, current wisdom implies that aviation will be dependent on liquid hydrocarbon ‘drop-in’ fuels for the long-term. In such a context, access to sustainably produced bio-based kerosene would be crucial to fuelling the future of aviation and enable the 2050 pledge to be delivered. Set against such a backcloth, the following considerations are noteworthy:

- Sustainable aviation fuels have the potential to play an important role in achieving Europe's ambition to reduce carbon emissions from transport, contributing to the EU 2030 climate policy goals and the global aviation target to halve net carbon emissions by 2050. The fulfilment of this potential, however, requires a new generation of advanced fuel technologies.
- Such new generation of advanced fuels must lead to step-changes in sustainability performance notably significantly reducing life cycle GHG emissions over fossil

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[102] IEA, 2013: Production Costs of Alternative Transportation Fuels - Influence of Crude Oil Price and Technology Maturity

[103] N. Winchester, D. McConnachie, C. Wollersheim, and I. A. Waitz (2013) Economic and emissions impacts of renewable fuel goals for aviation in the US. *Transportation Research Part A*, pp. 116-128

kerosene, meeting stringent sustainability standards and avoiding direct and Indirect Land Use Change (ILUC) such as tropical deforestation.

- However, to generate the necessary momentum for delivering such plans, aviation fuels will have to be considered from a more holistic perspective, which should foresee scenarios where aviation fuels would be produced alongside other high value products such as advanced diesel and other bio-chemicals to heighten their cost-effectiveness.
- The resulting economic benefits can be substantial. A study by E4tech for the UK[104] has estimated a potential global supply of up to 13 million tonnes of sustainable aviation fuel in 2030, equivalent to GHG emissions savings of 35 million tonnes of CO2eq. If appropriate support is made available, the UK could produce up to 640,000 tonnes of sustainable aviation fuel in 2030; this translates into around 12 sustainable fuel plants producing aviation fuel in combination with road transport fuels.

Lufthansa carried out a series of over 1000 flights between Hamburg and Frankfort with an A321, with one engine powered by a 50% HEFA biofuel blend and the other one with conventional jet fuel, allowing a direct comparison between both fuels and showing no negative impact of biofuels over the 6 months trial period.

British Airways (BA) and Rolls-Royce are developing a scientific test programme to find alternative fuels for the aviation industry. Advanced biofuels are capable of contributing to reducing the carbon intensity of the economy. However, their net contribution to reducing carbon must be assessed over the whole fuel cycle. They also raise broader environmental and social concerns over land use.

Several airlines, particularly KLM, have been running flights on a biofuel mixture partly based on cooking oil recycled from restaurants and hence demonstrating that this is a real possibility.

KLM is equally running the Green Lane Program testing weekly commercial flights between New York’s JFK and Amsterdam’s Schiphol airports using renewable fuel derived from waste oils. KLM and Schiphol Airport together with other government and industry partners are now engaged in launching “Bioport Holland”, with biofuel supply directly through the airport’s common fuel distribution system.

Some EU initiatives for the development of alternative fuels for aviation are shown in Appendix B.

The objectives are to be achieved in fields of feedstocks and sustainability along the entire value chain and life cycle; radical fuel concepts and fuel production technologies; technical compatibility, certification and deployment, as well as policies, incentives and regulation.

Initiatives for the use of sustainable advanced biofuels are also launched by IATA, the International Air Transport Association (Zschocke, 2011), ICAO, etc. For a good overview on the situation of biofuels for aviation, reference is made to the European Biofuels Technology Platform (EBTP, 2012) and to the IEA-bioenergy report (Rosillo-Calle, 2012).

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[104] Sustainable Aviation Fuels: Potential for the UK aviation industry, July 2014

Initiatives for the production of alternative jet fuels in the US include Altair, Emerald Biofuels, Fulcrum BioEnergy, Red Rock Biofuels. Altair and Fulcrum concluded long-term biojet fuel offtake agreements with United Airlines and Cathay Pacific.

Maritime vessels and inland waterway vessels can use many of existing biofuels, both blended in conventional diesel and as pure biofuels. Diesel fuels are the most common type of fuels used on board maritime vessels in the form of heavy fuel oil and marine gas oil, whereas Diesel EN 590 is generally used in inland navigation vessels. Among the available alternatives there are synthetic diesel, obtained from natural gas, soybean and rapeseed methyl ester and synthetic biodiesel obtainable from biomass.

Gaseous and liquid biofuels as well as bio-methanol could be alternative options for maritime transport. From a technical point of view, biodiesel blends (at small percentages) are a viable/promising option.

Concerns related to long-term storage stability of biofuels on board ships and issues of corrosion also need to be addressed. The testing of biofuels as marine bunker fuel has already started on board seagoing vessels, with the preliminary results being encouraging for their adoption.

5.4 Natural Gas and biomethane

5.4.1 Maturity of technology

Natural Gas Vehicles and all components are mature and fully OEM-developed. LNG vehicles differ slightly from CNG vehicles by possessing different storage tanks and a vaporiser to convert LNG to gas for use in the engine. Natural gas does not corrode an engine as much as petrol and so provides a longer engine life. Biomethane is a renewable version of natural gas and completely interchangeable with natural gas in an engine designed to burn methane. It is also possible to retrofit spark ignited (bi-fuel) and compression ignition engines (dual fuel) to run on natural gas. The potential to further decarbonise is significant, as existing engine technologies are based on gasoline and diesel engines, which are not yet fully optimised to run on natural gas, pure or blended with biomethane. Consequently, further efficiency gains are expected for light, medium and especially for heavy-duty vehicles in the next engine generations and years to come. Methane, blended with biomethane, offers the quickest and most cost efficient way for automotive manufacturers to lower their fleet's CO_2 emissions. However, OEM manufacturers could get more out of the high octane fuel natural gas, which could enable dedicated engines when purely operated with natural gas, since higher compression ratios can be used. To this aim, there are first results and an ongoing trend to achieve further improved energy efficiency when adopting the turbo-charging and direct injection, which can accommodate to the best boost pressure curve both when running on both CNG/biomethane and gasoline. In addition to that, efforts in areas like friction reduction, heat management, and combustion optimisation have the potential to achieve overall efficiency gains of 10% or more, which add to the powertrain benefits when using natural gas. Downsized gasoline powertrains, using turbocharger is the perfect way to achieve a high level of performance with low displacement engines. Research will strongly focus on further optimisation of heavy duty gas engines used in buses and trucks.

Future solutions will include optimised gas engines and hybrids using methane (city buses in Madrid and Malmö as well as LDV from Volkswagen are already existing), but the lack of CNG refuelling infrastructure still demands the co-existence of three fuels (petrol/diesel, gas and electricity). Due to the lack of room to lodge the relevant storage systems in nowadays vehicles, it is fundamentally important that vehicles should be running on gas exclusively, before CNG-hybrids will be commercially feasible. Therefore, the focus on improving the methane refuelling infrastructure will facilitate the expansion and optimisation of natural gas vehicles for both passenger and freight transport on short, (urban and regional), mid (inter-city and countrywide) and long distance (cross-border and heavy goods) transportation.

The state of the art technology is mature for the dedicated natural gas engines in cars, vans, buses and trucks. For medium/long distance and heavy duty transport, the LNG Blue Corridors is currently demonstrating the new Euro VI technology.

The technology applied on the gas truck engines from IVECO (100% gas) demonstrates the stoichiometric combustion with a three way catalyst can reach the Euro VI limits, even when considering low temperature cycles. Thanks to LNG/BIO LNG tanks fitted on the trucks, the energy density of natural gas and storage capacity is 5 times higher than for CNG. All these qualities apply also to Liquid Biomethane (bio LNG) or mixtures thereof with natural gas.

The LNG Blue Corridors project is supporting the development of the Euro VI technology, both in dedicated gas and Dual-Fuel engines (diesel and gas at the same time), aiming to demonstrate that LNG trucks (with significant higher range when compared to CNG) be a suitable replacement fuel for diesel at large scale. However the state of the art of gas engine performance has an output of maximum 340 HP and 1300 Nm. Long distance transportation, as demonstrated in the project in real operation and thanks to the close cooperation with several fleet operators which take part in the project, will demand more powerful engines above 400 HP New engines (both spark ignition and compressions ignition using HPDI) are currently under development and will be ready for 2016.

The use of LNG is becoming an important demand from the fleet operators, and development of the necessary infrastructure, is under way also with significant support from the CEF transport funds. High customer acceptance and satisfaction, two inherent objectives of the project, will ensure a strong LNG truck penetration all around the Corridors in the coming decades, therefore reducing oil imports and CO2 emissions at the same time. During the coming years the use of Euro VI methane/diesel solutions, like the one proposed by Volvo Trucks as part of the project and other companies, will further improve the vehicle offer of high horse power (>400 HP) applications. A rapid deployment of the LNG infrastructure will create confidence at both user/transport buyer and manufacturer level, a strong commitment by both is need to secure a cleaner mobility.

As with all new technologies, customers face problems to sell trucks to the second-hand market as well as to define a residual value for their trucks

The used NGV market is only starting to emerge in general, which in a transitional period, can hamper investment decisions, if it remains unclear how and where to sell used commercial vehicles to.

A wider network will support the CNG and LNG truck market development. At the same time a dense CNG infrastructure in cities will facilitate and support an increased share of CNG in buses, garbage trucks, delivery trucks and taxis (22.000 HDV units in European capital cities already). Passenger cars and vans need access to Natural Gas not only in in some cities and parts of Europe, but broader market uptake can only be assured if at least 10% of the existing infrastructure for conventional fuels would also include CNG refuelling facilities, at least along the TEN-T core network (to date less than 7% market penetration in more developed countries like Italy and Germany and hardly any stations in e.g. France and Poland).

5.4.2 Data on vehicles/infrastructure

There are around 1.2 million vehicles running on CNG representing 0.7% of the EU28 vehicle fleet including Switzerland, there or 75% of the market is Italy. More than 3,000 refuelling stations are available, 2/3 of which in Germany and Italy. 18 million vehicles are running in the world, representing 1.2% of the vehicle fleet worldwide. The distribution of vehicles and the infrastructure are shown in Table 5-6 for EU and EFTA countries.

Natural gas is the preferred alternative fuel by European OEMs, the current ex-factory CNG vehicle offer includes more than 30 passenger cars and light commercial vehicles (by Fiat, Lancia, Mercedes, Iveco, VW, Audi, Seat, Skoda and Opel and Volvo[105]), and keeps expanding, additionally all major bus and truck providers over CNG solutions EUR VI CNG buses are offered by Iveco, Scania, MAN, Mercedes (in 2015) and several smaller manufacturers. Iveco, Volvo, Renault, Mercedes and MAN Euro furthermore offer Euro VI CNG trucks. The current LNG vehicle offer in the EU is still limited, but keeps expanding. Iveco, Scania and Mercedes are offering EURO VI trucks already, Volvo, Renault and MAN will follow (see also Appendix D3).

There are approximately 1,500 EURO V and EURO VI LNG trucks and 55 refuelling stations. These figures clash with the high developments in China (240,000 LNG trucks and 2,400 stations) and in USA (more than 100 and 5,000 LNG trucks)[106]. The most important development in the EU is occurring in the United Kingdom, the Netherlands, Spain and Sweden.

Table 5-4: Current number of public CNG, and LNG/LCNG filling stations and number of gas-driven vehicles in EU and EFTA countries. Source: NVGA Europe 2015, http://map.ngva.eu

	CNG stations	LNG/LCNG stations	Gas Driven Vehicles
Austria	175	0	8.323
Belgium	20	3	1.033
Bulgaria	108	0	61.320
Croatia	3	0	329
Cyprus	-	0	-
Czech Republic	81	0	7.488
Denmark	7	0	104
Estonia	5	0	340
Finland	23	1	1.689
France	37	3	13.550
Germany	919	0	98.172
Greece	10	0	1.000
Hungary	5	0	5.118
Iceland	5	0	1.371

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[105]. Volvo Bi-Fuel cars are actually D-OEM (Delayed-OEM) solutions and in-house conversions that are commercialized and fully supported by the OEM. Not available in all European markets yet.
[106] GASNAM

	CNG stations	LNG/LCNG stations	Gas Driven Vehicles
Ireland	0	0	3
Italy	1.010	2	885.300
Latvia	1	0	29
Lichtenstein	3	0	143
Lithuania	1	0	380
Luxemburg	7	0	270
Malta	0	0	-
Netherlands	133	7	7.573
Norway	17	0	667
Poland	25	0	3.600
Portugal	3	3	586
Romania	0	0	-
Slovakia	10	0	1.426
Slovenia	3	1	58
Spain	45	15	3.990
Sweden	161	11	46.715
Switzerland	134	0	11.640
United Kingdom	7	13	718
Total EU+EFTA	2.953	55	1.156.687

One of the main initiatives of the EU to promote the market uptake of LNG in road transport is the "The LNG Blue corridors project" which involves the cooperation between heavy-duty vehicle manufacturers, fuel suppliers, fuel distributors and fleet operators. The project includes a first definition of European LNG Blue Corridors, with strategic LNG refuelling points in order to guarantee LNG availability for road transport. The core of the project is the roll-out and demonstration of four LNG Blue Corridors involving approximately 14 new LNG and L-CNG stations on critical points/locations in the Blue Corridors and a fleet of approx. 100 LNG Heavy Duty Vehicles operating along the corridors. The already installed LNG stations can be found on the Blue Corridor web-page: http://lngbc.eu/.

The map below shows the LNG infrastructure for medium and long distance transport by trucks (NGVA, 2014).

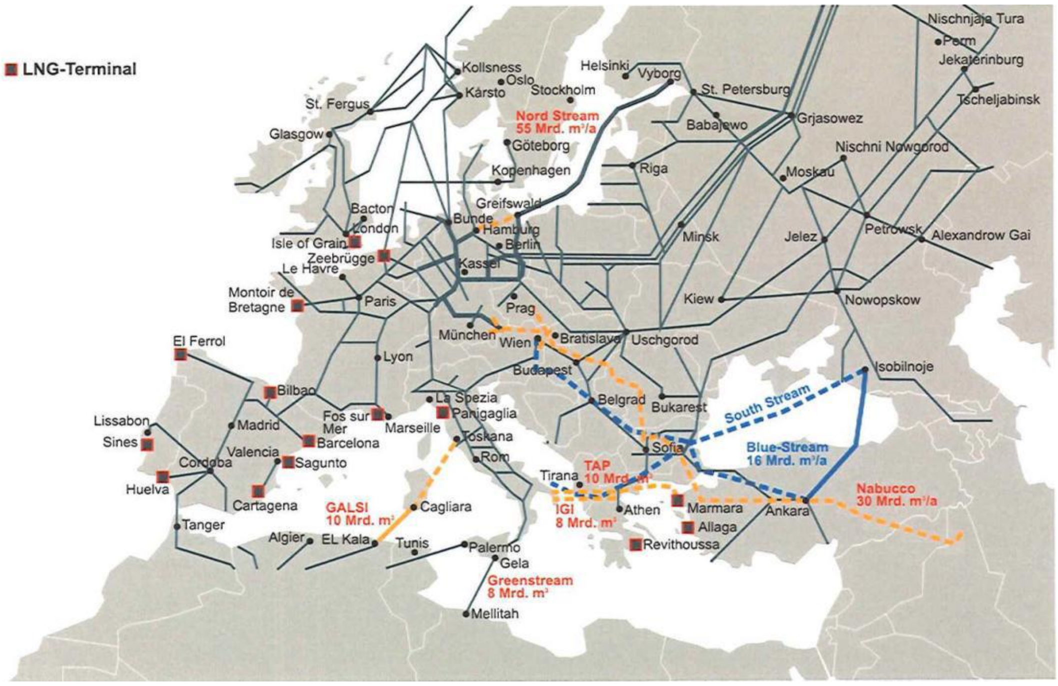

Figure 5-4: CNG core pipeline and LNG terminal network in Europe. Source: NGVA, 2014 [107]

Concerning the use of LNG in the maritime sector, Norway, Sweden, Finland Belgium and the Netherlands are the only European countries that have LNG refuelling facilities for vessels. Norway is leading to be followed by Finland currently making significant investments in new facilities. However, the construction of LNG refuelling facilities for vessels is planned for the next two or three years in Rostock (Germany), Gothenburg (Sweden) and Turku (Finland), Teesport (United Kingdom) and in the, Baltic States. Furthermore, France, Spain, Italy, Denmark and Greece have also plans for the near future.[108]

For the time being, all LNG bunkering of inland waterway vessels takes place from truck to ship, which requires designation of a specific bunkering area and amendment of port regulations. Currently, regular LNG bunkering of inland vessels takes place in the ports of Antwerp, Mannheim, Amsterdam, and Rotterdam.

Recent information from DNV GL and the Society for Gas as a Marine Fuel (SGMF) shows that 53 LNG fuelled ships are in operation in Europe (thereof 44 in Norway) with another 40+ in the order books (delivery up to 2018)[109] In addition to these there are a large variety of dual-fuel marine engines that support the use of LNG and diesel-oil.[110]

In the framework of its LNG project database for inland navigation, the CCNR[111] has knowledge of nine ports, which are currently planning or already implementing the development of LNG bunker stations that can be used for bunkering of inland vessels. These include the ports of Antwerp, Rotterdam, Hamburg, Bremerhaven, Mannheim, Basel and Ruse.

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[107] NVGA (2014), Natural Gas & Biomethane. Presentation Brussels 6. May 2014.

[108] See for example http://www.lngbunkering.org/lng/map/node for an overview.

[109] http://www.lngbunkering.org/lng/vessels/existing-fleet-orderbooks

[110] As outlined in semester project by Brenntrø, Garcia Agis and Thirion (2013) *Use of LNG in the Maritime Transport Industry*. Department of Petroleum Engineering and Applied Geophysics (IPT), NTNU

[111] Central Commission for the Navigation of the Rhine

In at least four other European ports with some inland or river-sea navigation, there are currently plans for LNG bunker stations, which are however mainly targeted to maritime or short-sea traffic. Whether they may also be used for the bunkering of inland or river-sea navigation vessels will depend on the design of these infrastructures and on the future demand from the IWT in these specific ports.

Currently, five LNG vessels are operating in inland waterways (four Dutch vessels and one Luxembourg vessel), and in addition 10 more vessels are ordered.

5.4.3 Cost of vehicles and infrastructure

Regarding the vehicle price, the additional cost is mainly determined by the CNG and LNG storage capacity. While passenger cars have a premium of 1,000-3,000 Euro versus the equivalent petrol version (more or less same price range as the diesel version), the extra investment in a CNG bus would be around 25,000 Euro compared with conventional diesel technology and the incremental cost for a LNG HD Vehicle compared with a regular diesel fuelled Heavy-Duty Vehicle is estimated at approximately 25,000-35.000 Euro, depending on storage capacity and engine output. (NGVA, 2015).

CNG passenger vehicles are offered to the market at prices slightly higher than the conventional fuelled cars. E.g. the VW Golf is offered as a CNG fuelled vehicle at a price between 23,825 Euro and 25,700 Euro compared to gasoline versions in the range of 19,375 Euro to 21,250 Euro and diesel alternatives in the range of 22,600 Euro to 24,625 Euro. In fact, the same reference model (110 hp, 4 doors) as diesel version costs 800,- EUR more than the CNG version, which explains that CNG is already becoming the more economic choice versus new Euro 6 diesel vehicles.[112]

This type of infrastructure can be fed from the existing natural gas grid. In this case, a compressor with the capacity of reaching a final pressure of 200 bars must be installed, and the dispensers. The total cost of this facility would be between 200,000 and 300,000 Euro depending on the compression capacity of the installation (normally 300-500 m³/h).

Provided the station would not be in the proximity of a pipeline, the laying of a natural gas pipeline connection to the station would become necessary and can vary depending on land characteristics (300-600 €/metre). In the case of a CNG depot station for buses or garbage trucks, the average investment for a single station will be around 1,000,000 Euro, due to the much higher capacity and storage needed.

This type of infrastructure supplying LNG can also supply both liquefied and compressed natural gas and biomethane. It has to be fed with liquefied natural gas via HD transport tankers.

LNG stations or L-CNG stations (also depending on capacity and size) would be in the range of 400.000-500.000 Euro for standard LNG station. Higher costs would apply when also taking into account acquisition of land, permits, etc. The upcoming standardisation of natural gas filling stations will have a significant impact on bringing down costs, as so far different LNG pressure levels have to be respected due to different existing technologies in the market, which can lead to substantially higher investments. It would be necessary to install a stationary LNG tanker to accumulate and feed the installation, a transfer pump to convert LNG into CNG (only in the case of

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[112] For similar levels of equipment, but variation due to e.g. specific motor size/technology, and number of doors

L-CNG), and the dispensers. The cost of the stationary tanker and the transfer pump is similar to the cost of a compressor. The maintenance of LNG/L-CNG stations would however be lower than in CNG stations.

For LNG refuelling points for vessels, this value can vary between EUR 15 and 20 million. Vessels can also be retrofitted to accommodate use of LNG. The costs of retrofitting is not known and also data on cost differences between LNG engines and conventional maritime diesel engines is unknown.

5.4.4 Perspectives for market development

The market take-up of CNG vehicles is still slow and the overall market share for vehicles still accounts for only 0.7% of all registered vehicles in Europe.[113] More and more ex-factory products from European manufactures are being introduced, but the sales of vehicles remain small. Significant technology investments on the OEM side (beyond Euro 6) support a very positive outlook for the vehicle market, which should reach 5% overall by 2020, with the potential to reach 10% by 2030 and >30% towards 2040. Concerning the LNG vehicle market, truck manufacturers estimate that 5-10% of the truck sales will be using LNG as a fuel in 5-10 years.

CNG The number of CNG and LNG vehicles offered and the technology is currently in a rapid development. Figure 5-5 illustrates the development in the CNG vehicle fleet size from 2004 to 2014. The fleet has tripled the last 10 years. and currently counts around 1,200,000 units. By 2020, more than 10 million vehicles are expected to run on Natural Gas and biomethane following current trends and growth rates. Actual sales of CNG vehicles in 2014 were approximately 150.000 across the EU (mainly in Italy) and are expected to increase steadily in the next five years. Particularly the share of CNG buses will increase significantly as the preferred technology choice for cities and urban mobility due to improved air Quality and CO2 performance. [114]

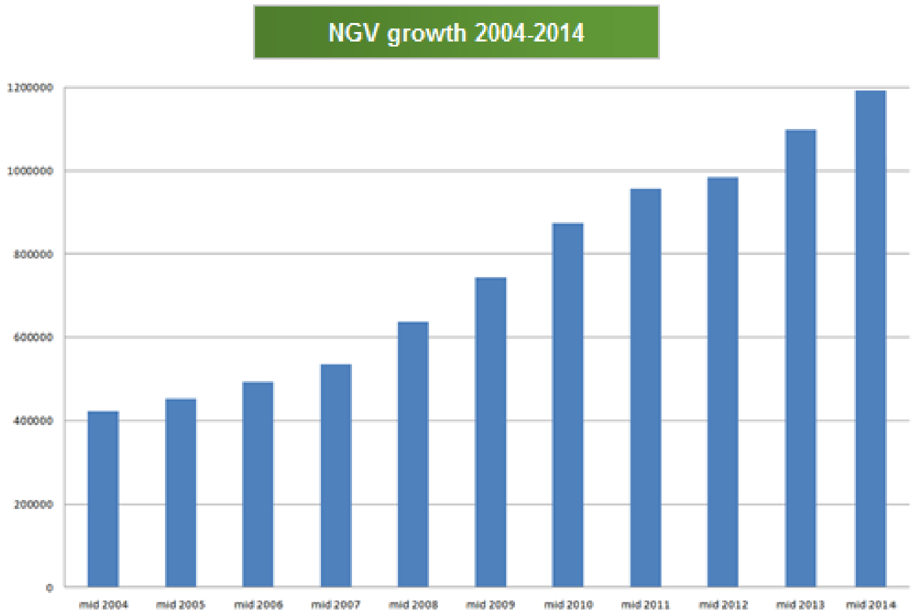

Figure 5-5: Natural Gas Vehicles in EU/EFTA from 2004-2014.

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[113] NGVA (2014) Contribution to the EGFTF meeting 6. May 2014.
[114] http://www.cenex.co.uk/wp-content/uploads/2015/02/670_013-2-Technology-Foresighting-Report-_-Final.pdf

The CNG fuel quality standardisation has been fragmented and carried out by the member states individually. First European drafts standards are under discussion and draft proposals have been issued recently. Currently three different standards are proposed. One for the gas grid quality (prEN16726:2014 E), another for the fuel quality injected into the gas grid (prEN 16723-1) and a third describing the automotive fuel quality for retailing at filling stations (prEN16723-1:2014 E). It is essential that the standardisation work delivers gas quality at the point of sale that is suitable for use in current and future technology gas engines.

For CNG a European automotive standard, well aligned with the existing grid standard, is urgently required. Ideally the parameters and limits posted in this paper are also applied to the grid and injection standards.

The development of LNG vehicles is at an earlier stage, and only in a test phase in a few countries.

In Figure 5-6 the amount of traded LNG is illustrated. It can be seen that the volume of LNG traded has grown steadily in the period 1990-2011. In 2011, the volume of traded LNG stagnated and the trade has not evolved significantly in recent years.

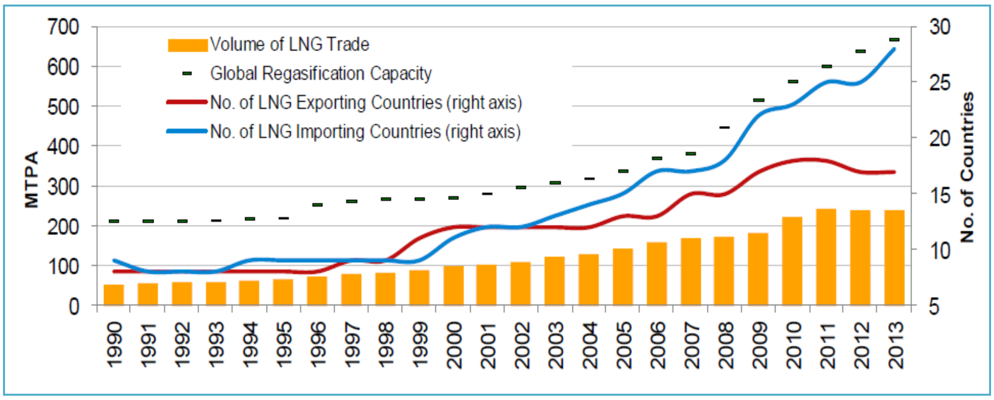

Figure 5-6: Volume of LNG Trade 1990-2013.

The imports of LNG as part of the total EU gas imports has even dropped from 19% in 2012 to 14% in 2013 (Eurogas statistical report 2014), but is expected to grow again in the future, mainly pushed by a growth of LNG demand and use for mainly maritime transport, which will however be linked to and depend on the development and expansion of refuelling infrastructure.

5.4.5 Other transport modes

Considerable efforts have been made to develop maritime engines that are able to run on natural gas, namely methane. The most promising alternative for use on board ships is natural gas. Methane for maritime use is normally stored in liquid form (liquefied natural gas, LNG) and burned either in stoichiometric or lean burn SI engines or on dual fuel engines.

Currently, across the world there are around 60 LNG fuelled vessels in operation, and more than 80 have been ordered excluding the LNG carriers (SGMF, 2015). It is expected that the LNG uptake will grow quickly in the next decades, with short-sea shipping being the key player in areas with developed gas bunkering infrastructure in the next five to 10 years. Deep-sea shipping will follow when bunkering infrastructure becomes available around the world. LNG bunkering for ships is currently only available in a number of places in Europe, Incheon (Korea) and Buenos Aires (Argentina), but the world's bunkering grid network is under constant development.

For maritime transport, the implementation of Directive 2012/33/EU of 21 November 2012 as regards the sulphur content of marine fuels is expected to be a driver for the promotion of LNG for ships.

Future LNG technology uptake in European inland navigation will depend on a number of factors, including the outcome of the ongoing revision of the EU non-road mobile machinery (NRMM) emission legislation, future development of LNG and diesel bunker price difference, development of gas engine and equipment prices, economic situation of IWT, availability of private and public funding for investments, and presence of incentive schemes. With the expected adoption of CCNR regulations for LNG propelled inland waterway vessels in 2015 an important condition for wider LNG implementation will be established. A possible extension of these provisions to the entire EU inland waterway network by means of EU legislation (Directive 2006/87/EC) as well as any advances in the standardization of LNG bunker stations, bunkering connections and LNG fuel quality could further support LNG uptake in the coming years.

Within the next two years, LNG bunker stations in the ports of Antwerp and Rotterdam are expected to become operational. This will significantly increase flexibility of LNG supply and might trigger new vessel projects. The picture for LNG supply in the hinterland is less certain: Feasibility studies are currently carried out by several inland ports in the framework of the TEN-T funded LNG Master plan Rhine-Main-Danube. In the best case, some of these ports could move to the implementation stage from 2016 onwards.[115]

In a modestly optimistic scenario, it could be expected that the rate of annual LNG new inland navigation vessels will gradually increase in the next years, complemented by a number of retrofits of existing vessels. Based on existing research (Panteia, 2013), mostly large vessels above 110 m in length and large new push boats are technically and economically suitable for being equipped with LNG propulsion. Finally, with increased LNG use in maritime transport, the number of LNG bunker vessels dedicated to port areas will also grow.

Considering the existing LNG supply chain infrastructure (import terminals, distribution facilities), current bunker station developments, traffic intensity as well as potential demand, until 2020 most of all LNG implementation activities can be expected to take place within the Rhine corridor between ARA seaports and Basel, Switzerland. Inland navigation is also ideally suited for the transport of LNG. LNG tank-vessels may serve as supply vessels for maritime vessels, for small-scale LNG installations in the hinterland and for regasification installations of land-locked countries. The safety regulations for the transport of LNG on inland waterway vessels (ADN regulation) is in place since beginning of 2015 and the first LNG supply vessels are under construction.

A huge potential for LNG lies in the rail sector, taking into account that 50% of the European railways are not electrified. Successful cases exist in the US and Canada. LNG will be particularly interesting for port handling equipment and shunting engines where LNG bunkering is available. Other off-road vehicles (including mining) would be suitable to run on natural gas or biomethane.

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[115] CCNR (2014): LNG Project Database, Observatory of European Inland Navigation, http://www.inland-navigation.org/observatory/innovation-technologies/lng/

5.5 Synthetic Fuels and Paraffinic Fuels

5.5.1 Maturity of technology

Paraffinic fuels, namely HVO, GTL and BTL are a class of high quality alternative fuels that can be used directly in diesel engines and/or blended with diesel, and are defined by CEN prEN 15940.

GTL and HVO production is mature, and are at an early stage of commercial use in Europe. HVO and GTL are currently produced at five commercial scale plants each around the world. Enough paraffinic fuels (GTL and HVO) are already produced today (24 million litres/day) to directly fuel 10 million cars or 250,000 buses – more than all diesel demand in the Netherlands for instance. The fuels have been tested and used commercially in heavy-duty on and off-road applications as well as passenger cars using both, neat form (100% paraffinic fuels) or high blending ratios (25-30% blending in diesel).

For example HVO is commercial in Finland for a 30% HVO blend in diesel in current vehicles. 300 buses run on HVO in the Helsinki Metropolitan Area Road tanker truck test in Finland from 2011 have testes trucks running with 100% HVO renewable diesel.

5.5.2 Data on vehicles/infrastructure

GTL is currently available for home-based fleets (i.e. with their own depots) in the Netherlands and Germany, and at retail sites in the Netherlands. Many fleets are running with neat GTL in current vehicles. In Sweden, Volvo has successfully tested 14 trucks running with bio DME under the FP7 project "BioDME". Volvo has started the commercialisation of these trucks. For the Swedish trial, four tanks have been in operation using technologies similar to LPG solutions for several of the components.

It is not necessary to build up dedicated infrastructure for synthetic fuels.

5.5.3 Cost of vehicles and infrastructure

Synthetic fuels can be used as substitutes for diesel, petrol and jet fuel with today's vehicle technology or with minor adaptations implying no substantial additional costs.

As regards fuelling stations, the additional costs determined by offering synthetic fuels would also be very limited when synthetic fuels are already blended with conventional fuels. While infrastructure can be used, there are additional costs to segregate fuelling pumps, trucks and tanks.

5.5.4 Perspectives for market development

Paraffinic fuels can be blended into normal diesel (EN 590) or used as 100% neat fuels (per CEN prEN 15940 specification), to reduce emissions of particulate matters and NOx. These fuels are available today in commercial quantities, and twice as many paraffinic fuel plants have been announced as exist today.

Neste Oil is part of a fleet demonstration programme for a new blend of diesel fuel in Coburg, Germany. The aim of the programme is to introduce to the market a fuel with a significantly higher proportion of renewable content than current diesel blends. The new blend, known as Diesel R33, contains 26% NExBTL[116] renewable diesel, an HVO-

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[116] NExt generation Biomass To Liquid

type fuel produced by Neste Oil, 7% conventional biodiesel (FAME) produced from used cooking oil, and 67% fossil diesel.

5.5.5 Other transport modes

For the **marine** segment, the Dutch Energy Vision estimates penetration for GTL as a fuel in the inland shipping sector of 11% by 2030 and 19% by 2050, and in recreational vessels of 19% in 2030 and 31% in 2050.

The attractive features of methanol relate to its chemical properties: it does not contain any sulphur providing a solution for IMO emission control areas (ECAs); is at liquid form at room temperature, without needing cryogenic or pressurised storage; thus, conventional and cheaper storage equipment is required.

Methanol can be used for waterborne transport for inland as well as for short-sea shipping, where it is currently being tested. Stena line has for example early 2015 rebuilt one of four 6 MW engines on a large ferry (Stena Germanica) to operate on methanol. The ferry is put back in service in April. The other three engines will be converted during the summer 2015.

Methanol has almost the same heating value as diesel or LNG (LNG with 20.3 MJ/liter and methanol has 19.8), which entails a similar performance compared to other marine fuel alternatives like LNG. However, marine engine manufacturers claim that the conversion of an existing engine to burn methanol would bear less costs than an LNG retrofit work, since there are no dead volumes, no insulation requirements etc. Hence, methanol is easier to handle compared to LNG. In July 2013, the classification society DNV released rules for using low flashpoint liquid (LFL) fuels, such as methanol as bunker fuel. Interest in methanol as ship fuel is growing in response to the need to reduce SO_x emissions. In northern Europe and around the north American coast. A Canadian company has e.g. decided to invest in six new methanol driven 50,000 dwt tankers.[117]

5.6 Liquefied Petroleum Gas (LPG)

5.6.1 Maturity of technology and barriers

LPG is fuelled in a slightly modified spark ignited internal combustion engine. A significant number of manufacturers offer more than 50 different models of vehicles including passenger cars and vans.

The standards for fuel and refuelling stations already exist. The EN 589 defines the specifications for automotive LPG. This standard has become mandatory in several Member States. The industry has also defined a voluntary standard (EN 14678), which outlines technical and safety requirements for autogas filling stations. The LPG industry is currently in the process of revising the standard to include specific requirements for un-manned stations and multi-dispensers. Four different types of filling nozzle are used across Europe. The Euro connector (EN 13760) was adopted in 2003 but has only shown limited uptake, while generally being appreciated by the customers for its ease of use and low emissions.

Currently, vehicle manufacturers are looking closer at LPG in order to evaluate further advantageous properties over gasoline. Turbo-supercharged direct injection engines have shown to hold the greatest promise to unlock the full potential of LPG. The

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[117] http://shipandbunker.com/news/am/137327

relatively high knock resistance and the excellent atomisation lead to a clean and efficient combustion delaying the point at which engines need to retard spark timing and heavily enrich mixtures to prevent damage (AEGPL, 2014).

There are approximately 7.4 million LPG vehicles on the EU market. The core infrastructure is already established, as LPG is used, in addition to the transport sector, also in domestic, industrial, and other sectors. More than 30,000 public filling stations for LPG are in service in EU28. The distribution is somewhat skewed with many vehicles and stations in some Eastern European countries (e.g. Bulgaria, Poland, Czech Republic and Lithuania) as well as in Germany, the Netherlands and especially Italy, whereas the numbers are very low in Denmark, Ireland, Estonia, Finland, Malta, Norway and Sweden.

Transporting LPG across the whole distribution chain, from the production site to the refuelling stations can include a combination of pipelines, deep sea/coastal tankers, rail tank cars, and bulk road tank cars.

5.6.2 Cost of vehicles and infrastructure

LPG vehicles are being offered either as bi-fuelled OEM vehicles (mono-fuelled only outside of the EU) or as after-market conversions. The premium for an OEM LPG version ranges from EUR 800 up to 2000 while it costs between EUR 1400 and 3000 to perform a conversion. The associated cost for installing an LPG filling station is between EUR 75,000 and EUR 200,000.

Table 5-5 The number of LPG fuelled vehicles and the number of LPG stations in the EU. Source: AEPGL

Country	Vehicles	Stations
Austria	7,000	40
Belgium & Lux	50,000	725
Bulgaria	470,000	2,970
Croatia	85,000	324
Czech Republic	170.000	1.185
Denmark	80	5
Estonia	1.000	20
Finland	0	0
France	262.000	1.750
Germany	501.000	6.750
Greece	220.000	590
Hungary	55.000	330
Ireland	2.500	57
Italy	1.930.000	3.250
Latvia	48.368	205
Lithuania	210.000	480
Malta	45	3
Netherlands	204.315	1.850
Norway	3.025	235
Poland	2.750.000	5.520
Portugal	47.500	280

Romania	195.000	1.205
Slovakia	15.000	207
Slovenia	10.500	75
Spain	28.049	574
Sweden	105	33
UK	150.000	1.711
EU	7.415.487	30.374

5.6.3 Perspectives for market development

Being co-produced in many different fuel production and synthesis processes, the technological risk is fairly low. Many different scenarios include sufficient production volumes of LPG. A significant advantage for the market uptake of LPG is that with only moderate excise duty reductions, the price of LPG can be maintained on average at about half the price of gasoline or diesel. Most countries, where LPG has been introduced with success have made long term commitments to maintain a lowered excise duty level.

5.6.4 Other transport modes

Mainly used as a fuel for passenger cars, LPG can also be used to fuel a variety of other vehicles.

For the transport of goods on roads, light duty vehicles based on passenger car technology (sharing engines of the same power range and platforms) can easily be designed / adapted to use LPG as a fuel. The Ford Transit Connect (LPG) is a good example where this is already being done with success around the world; However, this is not yet available in the EU.

The combination of diesel and LPG (dual fuel technology) has enjoyed some success with heavy duty vehicles. Here the use of LPG can reduce the emissions of CO_2, NO_X and particles. Dual fuel technology is intended to supplement the existing fuel instead of completely replacing it.

Marine engine manufacturers like MAN offer dual fuel engines that can be operated with LPG as well as marine fuel oil. However, special safety considerations, especially designs for fuel tanks and piping are required. LPG has been identified as possible alternative fuel, supplementary fuel for short sea shipping. The segment of recreational vessels has seen the entry into market of at least one dedicated manufacturer of LPG-outboard engines. LPG is not considered a likely alternative for the (deep-sea, offshore) maritime sector except in large LPG transports. (A batch of four tankers in the 35,000 cbm class have been ordered and the first is planned to be commissioned during 2015). For safety reasons the and inland waterway navigation sector does still not consider LPG as an alternative for this sector.

Successful experiments have also been conducted with recreational aircraft, where fuel for spark ignited engines still contains considerable amounts of lead as an octane booster. The different projects looked into the options for fuel which exhibited better long term storage capacity and less environmental impact and were conducted at different times. They have proven the basic feasibility but have not been pursued any further.

6 Synthetic presentation of results

6.1 Availability

Electricity can be produced from all primary sources; it is becoming increasingly low carbon. Under current trends and adopted policies, the share of electricity generation from renewable energy sources (RES-E indicator[118]) is projected to go up from 20% in 2010 to about 43% by 2030 and 50% by 2050 (European Commission, 2013). In this context, extending electricity use in the transport sector will contribute to emissions reduction, fuel diversification and improved air quality.

The potential for hydrogen as a fuel is significant as it can be produced from a variety of primary energy sources. Currently, hydrogen is predominantly produced by steam reforming of methane. However, it can also be produced from low carbon energy sources using electrolysis. Many production processes for hydrogen have been state-of-the-art for a long time. Hydrogen is already produced in large quantities for industrial applications. The cost of production and energy efficiency can still be improved. In addition, significant investments would be needed in the distribution network for hydrogen.

Most of today's biofuels are produced from agricultural crops like maize, sugar cane and rapeseed. In the future, the share of second- and third generation biofuels made from lignocellulosic biomass, residues, waste, and other non-food biomass, including algae, sewage sludge and microorganisms will increase. However, the potential of biofuels will be limited by the availability of land, water, energy, and sustainability considerations.

Synthetic fuels, substituting diesel and jet fuel, can be produced from different feedstock, converting mainly biomass or gas into paraffinic liquid fuel. Hydrotreated vegetable oils (HVO), of a similar paraffinic nature, can be produced by hydrotreating plant oils and animal fats. Ten commercial scale HVO or GTL production plants are currently in operation.

The natural gas worldwide reserves have increased by up to a factor of three in recent years due to the use of new drilling techniques and to the discovery of sources of unconventional gas. Proven reserves will last considerably longer than those of oil (beyond 200 years) and transport is a new growth market for gas, while other markets are expected to decline over time. EU natural gas imports account for 45%, which could be further mitigated in the mid-term by an increased production of biomethane.

Liquefied Petroleum Gas (LPG) is one of the products of the hydrocarbon fuel chain, currently resulting predominantly from oil and natural gas refining, in future the shares being co-produced from biomass are also going to be marketed. LPG availability is likely to increase as a result of an increasing oil and natural gas production worldwide. Bio-LPG derived from renewable sources (co-product of fuel synthesis) can increase the supply of LPG in the mid-term. Bio-LPG derived from renewable sources (co--product of fuel synthesis) can increase the supply of LPG in the mid-term.

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[118] Calculated according to the definitions of the Renewable Energy Directive (Directive 2009/28/EC).

6.1.1 Maturity of the technology

The large scale introduction of electric vehicles will be linked to developments in the battery's energy density, which would extend the driving range of electric vehicles. Another concern is the duration of battery life and its cost. Fast charging facilities and reductions in purchase prices will also be important to accelerate the market development of electric vehicles.

FCEV vehicles have a satisfactory range and performance. The industry is currently focusing on optimising the duration of the life of fuel cells and costs. The lack of availability of infrastructure and low awareness among public represent a major barrier that needs to be addressed The limited EU refuelling network is an additional constraint.

Blending biofuels with fossil fuels not exceeding the limits specified by the Fuel Quality Directive (10% ethanol in E10, and 7% biodiesel in B7) has the advantage that neither new engines nor new infrastructure is necessary. Higher percentages of ethanol and biodiesel contents in blends may require some adaptations to certain vehicles, including engine and exhaust treatment designs. Some industries are considering higher contents of ethanol blends, but the focus is rather on the performance of the blends through e.g. the octane. The industry further wants to stay with B7. B30 could be an option for use with captive fleets of dedicated HDV.

Paraffinic fuels (GTL, HVO and BTL) do not require the development of any vehicle technology, as they are fungible with fossil diesel in any blend ratio (0-100%).

Natural gas vehicles (CNG, biomethane) are based on a mature technology, using conventional internal combustion engines. A reasonable choice of vehicles has been developed in recent years. LNG Euro VI trucks are now starting their accession to the market.

LPG is fuelled in slightly modified spark ignited internal combustion engines. The technology is mature and readily available.

6.1.2 Vehicles and infrastructure

The share of alternative fuel vehicles is above 4% of the EU market.[119] LPG is the most used technology followed by CNG. Biofuels are mainly used in low blends with petrol or diesel. Significant developments have occurred for BEV and PHEV vehicles in the last year. However, for battery electric vehicles the main constraints remain the range (most vehicles cannot go beyond 160 km), the battery life, in particular during winter and the battery system cost. The market development of FCEV, synthetic fuels remains limited. The number of LNG vehicles is now developing thanks to the LNG Blue Corridor project and industry initiatives.

The reported numbers of road vehicles are summarised in Table 6-1 for the whole EU. These numbers continue to grow month by month as new vehicles are entering the market.

Table 6-1: Summary of number of vehicles and public refuelling stations.

Alternative fuel	Vehicles	Refuelling stations

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[119] Source: Eurostat Pocketbooks; Energy, transport and environment indicators, 2013 Edition. http://ec.europa.eu/eurostat/documents/3930297/5968878/KS-DK-13-001-EN.PDF/5ca19637-b2fd-4383-98a3-629ec344c283 Table 2.6.6

BEV	114,4840	>40,000
PHEV	63,959	
FCEV	167	200
Biofuels*	>205.000	
CNG and biomethane	1,156,687	2953
Synthetic fuels and paraffinic**	Est. 1,000 - 5,000 (GTL or HVO)	>50 sites + home-base depots + 3 bunker stations
LPG	7.415.487	30.374

* Most of the registered biofuel vehicles are running on E85 (mainly in Sweden). Most biofuels are blend-in fuels such as E10 and B7, which in most cases can be used in conventional gasoline and diesel cars. ** Figures are for segregated paraffinic fuels. Paraffinic fuels are also being blended into standard diesel.

Infrastructure Regarding alternative fuel infrastructure, the number of electric recharging points is continuously growing. There are currently more than 40,000 recharging points in Europe(private and public). The charging points are not all interoperable in terms of connectors and protocol of communication The number of hydrogen fuelling stations remain low despite expectations of the sector, however, the stations can accommodate many customers similar to conventional fuel stations. High-blend biofuels fuelling stations are mainly used for public fleets. E10 pumps are only available in Finland, France, and Germany. E85 pumps are mostly present in Sweden. CNG refuelling points are more numerous in Germany and Italy and better density already exists in Austria, Czech Republic, the Netherlands, Sweden and Switzerland, whereas they are hardly present in a large number of Member States. As to LNG, less than 100 refuelling stations exist, while acknowledging that markets like the UK, followed by Spain, the Netherlands and Sweden are more developed. This scarcity prevents the mobility of LNG trucks across the EU. Paraffinic fuels (GTL and HVO) can be blended into diesel and distributed as usual, or can be segregated for neat or high-blend use; currently these fuels are available to customer fleets via home bases and at certain refuelling sites.

Several alternative fuels are being tested for maritime and inland navigation use. The main focus has been on LNG for these sectors, but, batteries hybridisation, biofuel blends and GTL are also being considered, and refurbished ships aimed at testing methanol is under way. A small number of day-trip inland vessels with fuel cells have been built, mainly as technology demonstrators. GTL has been shown to reduce emissions, smoke and smell in this segment. The choices and possibilities very much depend on the water transport type (deap sea, short sea, inland etc.) and the ship size. Significant developments are planned for LNG refuelling points in different maritime and inland ports throughout Europe for the next years. However, availability, price and investment considerations remain critical in the large scale use of alternative fuels and in the short term only a limited uptake can be expected (Acciaro 2015). Inland navigation vessels may supply small-scale LNG installations in the hinterland and regasification installations of land-locked countries.

LPG infrastructure has been put in place in many Member States. 30,000 refuelling points already exist, but their distribution is quite diverse. Cross-border continuity needs to be ensured if an international continuity in infrastructure is to be obtained.

6.1.3 Production costs for fuels, vehicles and infrastructure

The production costs of BEVs, PHEVs and FCEVs are currently rather high. This is due to the relative immaturity of the production technologies and to the absence of mass production, especially for FCEV.

BEV's and PHEVs can have a TCO equivalent to ICE vehicles if intensively used.

According to JCH-JU (2012), the total costs of ownership (TCO) for FCEV and BEV is expected to converge with ICE after 2025. However, current low oil prices can change this relation, market reality is furthermore drawing a rather different picture. JCH-JU (2012) have used average oil and electricity prices from IEA World Energy Outlook 2009 with a price of 100 $ per barrel in 2010 increasing to 134 $ in 2050.

For biofuels, the cost of the vehicles/planes and infrastructure is not a barrier to their market introduction in all modes of transport because biofuels have the advantage of compatibility with the existing fuel distribution infrastructure, up to certain blending limits. Concerning conventional biofuels (ethanol, fatty acid methyl esters) low blends do not need additional infrastructure. Higher blends require some adaptations to the vehicle, notably engine and fuel line materials, and to the existing infrastructures.

For second and third generation biofuels the main barrier to their development is the lack of long-term incentives and indecision in the politics of Brussels that has effectively stopped long-term research into the more widespread use and availability of advanced biofuels. Second and third generation biofuels can cost wise compete with first generation but because the capital cost share of the production costs is larger for advanced biofuels and the total cost for a single investment is higher, long term, firm incentives are a must to make the projects bankable. Compare how support structure for wind power has been in force for a long period in Germany. Feed-in tariffs have been granted for a long operating period, 15-20 years. Without this type of long term stable role the wind mill investment program would not have taken place to the extent it has. The mills would not have been bankable (this comparison does not imply that feed in tariffs is a suitable mechanism for biofuels).

The cost of vehicles and infrastructure are not barriers to the synthetic fuels; however before achieving market scale, demonstration costs and logistics costs of a segregated supply chain are higher than for conventional diesel. For HVO the main barrier remains the production cost of the fuel itself.

The present lower cost of CNG and LNG at the pump than petrol or diesel facilitates the payback of vehicle purchase costs .Therefore, the higher cost of vehicles should not represent a main barrier to the introduction of these fuels in the market. However, there are incremental costs for Heavy Duty Vehicles (HDV), particularly trucks, which are expected to come down with economy of scale. For CNG, an EU-wide network of CNG refuelling points is missing, which is the main barrier for the market development of CNG vehicles. Despite, higher investment costs for CNG refuelling points in the range of 5-7 times more than that of conventional fuels, the investment in CNG stations is lower than for other alternative fuels. The development of infrastructure for using LNG as a truck fuel can be tackled by the industry, if there is sufficient certainty about the future volume of the market and if interoperability is ensured. Additional support is provided from CEF transport funds, but additional support for customers to purchase vehicles is needed to develop critical mass. The biomethane price at the pump would need to be the same as the CNG price, in order to be economically feasible and competitive. However, since, the physical product is the same, via blends of CNG and biomethane, the market for natural gas and biomethane will constantly grow. But as for the second and third generation biofuels there is also a barrier for the development of biomethane and SNG as well as hydrogen is the lack of long-term incentives and indecision in the politics of Brussels.

For LPG, infrastructure is sufficiently developed in many EU Member States, but with exception of Denmark, Ireland, Estonia, Finland, Malta, Norway and Sweden.

6.1.4 Emissions and energy efficiency

The GHG emissions presented in the report are based on the Well to Wheels report (JEC, 2014b), although other contributions to measure GHG emissions exist - none of which is as comprehensive as the JEC WTW report. However, there are critics of the JEC approach especially when considering natural gas and bi-methane, moreover also that the study only represents passenger road transport is a problem. Emissions and energy consumption are shown for a theoretical passenger vehicle type representative of the European passenger car fleet. The emissions cover only passenger cars (especially the TTW figures) and figures for trucks and other modes are hence missing. The WTT figures may also be relevant to other transport modes since there is no relation to the km in the calculations and thus no reference to the specific vehicles. On the use side (TTW) the emissions and energy consumption figures relate to the vehicle cannot be transferred to other modes.

JEC (2014b) does not include local air pollutants and there is no single reference source of information about this. For electromobility, the tail pipe emissions (TTW) are zero, but there are still some emissions from the production of electricity depending on the electricity production. For paraffinic fuels, substantial test and real world data shows reductions in PM, NOx, HC, and CO emissions. More and more stringent Euro limits have entered into force, real driving emissions of some pollutants have failed to reduce sufficiently to solve air quality problems (particularly for diesel engines).

Table 6-2: Overview of WTT, TTW and WTW GHG emissions. Source: JEC (2014b) Appendix 1

Alternative fuel	**WTT g CO_2/km**	**TTW g CO_2/km**	**WTW g CO_2/km**
Conventional gasoline	29	156	185
Conventional diesel	25	120	145
BEV EU28 Mix	78	0	78
PHEV EU28 Mix (Gasoline/Diesel)	38	75 / 68	111 / 105
FCEV Thermal gasification path EU28 Mix	62	0	62
FCEV Electrolysis path, EU28 electricity mix	125	0	125
Bio-diesel/B7	-101 to -22 / 14-19	125 / 181-184	44-103/137-140
E10 / E20/E85	17 – 28 / 6-28 / -82 to 29	150 / 148 / 143	168-178/154-176/61-171
CNG (EU mix)	30	132	163
Biomethane	- 290 to -33	132	-158 to 99
HVO	-111 to -22	116	5-94
GTL	22 – 38	116	138-154
CTL	65 – 211	116	181 - 328
Wood	104 to -111	116	12
DME (natural gas/Coal /BTL)	38 / 218 / -104	117 / 117 / 117	137-154 / 334 / 12
LPG	17	142	160

An overview of the GHG emissions measured as WTT, TTW and WTW is given in Table 6-2. The figures presented give a range of the emissions for the fuels. It is not possible to give a complete overview of all possible combinations of fuel production paths and vehicle configurations; for further details JEC (2014b) should be consulted.

For some biofuels and paraffinic and synthetic fuels GHG emission can be negative, which is related to the production path ensuring that GHG is not emitted directly from e.g. biomass.[120]

The corresponding energy consumption both as WTT, WTW and TTW based on JEC (2014b) is shown in Table 6-3. In the table the share of the energy coming from non-fossil is indicated as the WTW energy consumption in MJ per 100 km.

Table 6-3: Overview of WTT, TTW and WTW energy use. Source: JEC (2014b) Appendix 1

Alternative fuel	**WTT MJ/100km**	**TTW MJ/ 100 km**	**WTW MJ/ 100 km**	**WTW from non-fossil fuels MJ / 100 km**
Conventional gasoline	39	211	250	0
Conventional diesel	33	163	196	0
BEV EU28 Mix	118	52	170	132
PHEV EU28 Mix (Gasoline/Diesel)	52 / 53	116 / 107 (TTW from fuel + TTW from electricity)	168 / 159	38
FCEV Thermal gasification path EU28 Mix	53	54 (TTW from fuel)	107	10
FCEV Electrolysis path EU28 Mix	218	54 (TTW from fuel)	272	198
Bio-diesel / B7	45 – 437 / 31-56	163 / 163	207 - 600 / 193 - 219	154 – 509 / 12 - 34
E10 / E20 / E85	48 – 64 / 58 – 91 / 142 – 312	204 / 201 / 199	252 - 268 / 261 - 284 / 341 - 459	24 – 40 / 52 – 85 / 224 - 421
CNG (EU mix)	38	232	271	8
Biomethane	231 - 503	232	463 - 736	421 – 701
HVO	26 – 407	163	188 - 570	167 – 504
GTL	103 115	163	265 - 277	1
CTL	157 – 171	163	319 – 333	5
BTL	148 - 195	163	357	347
DME (natural gas/Coal/Wood)	92 / 163 / 184	172 / 172 / 172	264 / 334 / 356	2 / 12 / 346
LPG	26	216	241	0

The emission and energy consumption figures for all other modes of transport are not shown. However, the WTT emissions and energy consumption figures are in many cases the same, as also indicated above.

On WTW basis, both energy efficiency and GHG intensity of BEV, PHEV and FCEV is better compared with conventional fuels, in particular compared with diesel. Significant reductions of GHG emissions can be obtained with natural gas if blended with biomethane.

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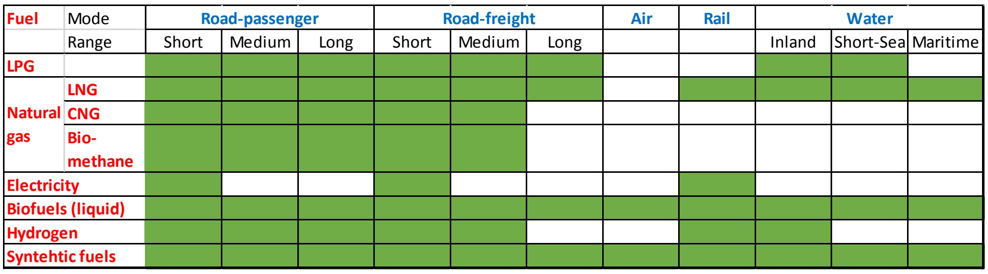
[120] For example if methane is removed from fertilizer before it is distributed on crop fields.

6.1.5 **Fuels and transport sectors**

Although all fuels are in principle usable in all transport sectors, this is not the case in practice. In the first EGFTF report, the link between fuel and transport modes shown in Figure 6-1 was presented in an earlier version. It has been slightly updated for the current report. Recently, with the longer ranges in e.g. the Tesla S model, electric vehicles may also extend into medium and long ranges.



Fuel	Mode	Road-passenger			Road-freight			Air	Rail	Water		
	Range	Short	Medium	Long	Short	Medium	Long			Inland	Short-Sea	Maritime
LPG		🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	
Natural gas	LNG	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩
	CNG	🟩	🟩	🟩	🟩	🟩						
	Bio-methane	🟩	🟩	🟩	🟩	🟩						
Electricity		🟩			🟩				🟩			
Biofuels (liquid)		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Hydrogen		🟩	🟩	🟩	🟩	🟩			🟩	🟩		
Syntehtic fuels		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Figure 6-1: Modes and Range for alternative fuel types. Source: Adaptions from 1st Report of EGFTF, 2011

The table shows that for short-range road transport, all fuels can potentially be applied and a number of them are already used.

Nevertheless, it is important to extend the use of alternative fuels to other transport modes, where technologically feasible, to achieve a 60% reduction of GHG emissions from transport by 2050. In this respect, alternative fuels are being tested across the modes and new developments are taking place.

All electrical vehicles have a significant potential to reduce GHG and local emissions, assuming GHG reduction is performed at the production site. Battery driven electric ferries and air planes are being tested. New battery and fuel cell technologies will have the potential to open up completely new horizons for all transport modes. In particular, advancements in nanomaterials, including lithium-ion batteries, reversible hydrogen storage options, nanomaterials in fuel cells and thin-film batteries will all contribute to the expected developments.[121]

Fuel cell electric vehicles with a driving range and performance comparable to internal combustion engines can be among the best low-carbon solutions for medium/larger cars and longer trips. Today, these car segments account for about 50% of all cars and 75% of CO_2 emissions. Fuel cell and hydrogen have also a lot of applications in aviation and maritime applications.

Biofuels are suitable for all modes of transport. The new generation of advanced fuels must lead to step-changes in sustainability performance, notably by significantly reducing life cycle GHG emissions over fossil fuels, including kerosene, meeting stringent sustainability standards and avoiding direct and Indirect Land Use Change (ILUC).

Synthetic fuels have to a large extent the same properties and can be used as blend in fuels, and do therefore have the possibility to substitute the conventional fuels used for all modes of transport. Many of the synthetic fuels are used or are being tested in various forms and in different modes of transport.

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[121] *Predictions of Innovations*. Thomson-Reuters, September 2014

New developments in natural gas powertrains and the future adoption of the CEN standard being developed by CEN/TC 408 for "Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network" will be key to widespread use of natural gas and biomethane in transport. CNG in urban mobility (mainly heavy duty vehicles and taxis) and LNG used in heavy-duty vehicles is the most attractive option to mitigate the high dependence of the European Union on diesel and to accomplish the limit of 0.1% sulphur content in marine fuels established by the Directive 2012/33/EU. In the medium term, LNG seems to be the most promising available alternative fuel for inland waterway transport, considering that LNG propulsion technology is ready for application and has successfully been deployed on inland vessels since 2011. Further research and demonstration need to address above all methane slip due to its climate effect.

LPG will mainly be used in passenger cars and light duty vehicles but could also be used in heavy-duty vehicles. Moreover, LPG could have a role in maritime and inland navigation.

One important parameter with respect to changes in fuel types for various type of transportation modes is energy density and the complexity of the fuels storage as such. Many of the fuels are very similar as the current commercial types but especially when going from liquids to gases the energy density plays an important role. E.g. hydrogen at 800 bar carries 13% of the energy compared to diesel on a volumetric basis. This is only covering the energy in the volumes of fuel. When it comes to vessel shapes, degree of maximum filling volume and eventual need for insulation this is not taken into account. Thus energy density has a major impact on cost of fuel tank, driver distance etc.

7 Policy and non-policy recommendations

The EG FTF has made the recommendations here below for the consideration by:

- the Commission, the Council of the Union and the European Parliament
- the Member States
- the European Committee for Standardisation
- the EU industry.

7.1 Policy approach

The use of alternative fuels in transport will be a key factor for the EU economic growth & employment and for the industrial competitiveness in the next years. Alternative fuels have the potential to play an important role in achieving Europe's objectives to reduce GHG emissions from transport by 60% by 2050 relative to 1990, contributing to the EU 2030 climate and energy policy goals. Therefore there is a need for a long term, technology neutral, stable and ambitious policy framework to give confidence to the industry in order to make the necessary investments to promote alternative fuel transport systems and the related infrastructure. In this respect, as already indicated in the former report from the Group, policy initiatives should be technologically neutral, founded on a scientific assessment of *well-to-wheel* and regulated pollutant emissions, energy efficiency and costs associated with competing technologies

A significant market uptake for alternative fuels for all modes of transport can only be achieved if all the relevant actors in the value chain – public and private - take steps to develop a coherent, joint, over-arching strategy that can deliver the proposed long-term goals that enables a profitable business for fuel providers, infrastructure operators as well as vehicle manufacturers and customers if there is sufficient public acceptance

In the following sections different measures that are among the actions required to support the market uptake of alternative fuel transport systems and the relevant infrastructures are described

7.2 Implementation of the Directive on the Deployment of Alternative Fuels Infrastructure

The Commission should:

- be guided by the principle of EU-wide harmonization, i.e. national differences (taxation, incentives, fuel standards) must be avoided to achieve integrity of the common market
- elaborate the guidance documents to facilitate Member States with the drafting of their National Policy Frameworks and a common methodology for alternative fuels unit price comparison as soon as possible
- after the analysis of the National Policy Frameworks for the implementation of Article 3 of the Directive on the deployment of alternative fuels infrastructure, consider proposing achievable minimum targets under the next review of the Directive on the deployment of alternative fuels infrastructure envisaged for 2018
- set up a platform including Member States' industries, civil society and financial actors to ensure that programmes and policies cover the whole range of subjects and that suitable and safe solutions are found to ensure the deployment of alternative transport systems and the relevant infrastructure in the EU.

The EU legislators should implement an EU-wide-colour-coding scheme for fuel labelling for all alternative fuels across the EU. This scheme should be simple, clearly visible and easily understandable, and should be placed in a corresponding manner at both the fuel pump and the vehicles to allow easy recognition by consumers of fuel compatibility with their vehicles.

Member States should:

- define appropriate national targets and objectives in their National Policy Frameworks for the implementation of Article 3 of the Directive on the deployment of alternative fuels infrastructure. These national targets and objectives should ensure a minimum endowment of alternative fuels infrastructure to guarantee EU-wide mobility with alternative fuel vehicles and vessels taking account of the specific needs of isolated and/or rural areas
- consider the inclusion of other alternative fuels than those mandated in the Directive on the deployment of alternative fuels infrastructure in their National Policy Frameworks, in particular to ensure cross-border mobility with their neighbour countries
- carefully chose the location of recharging and refuelling points to best accommodate the initially small vehicle or vessel numbers and to create maximum impact in early stages of deployment. To this end, coordinated roll-out of vehicles and infrastructure will be necessary
- encourage investors and operators of refuelling stations to offer alternative fuels together with petrol and diesel, on the basis of an analysis of market-demand and/or the technical (including health and safety) and financial implications involved. This also applies to port infrastructures due to their central part in the European transport corridors
- report on an annual basis the number of alternative fuel vehicles and vessels registrations, average fuel prices and total consumption of each alternative fuel for the transport sector by mode
- Manufacturers and shipyards should offer alternative fuel vehicles and vessels as part of their range of products. This recommendation should also apply to non-European brands importing vehicles into the EU.

7.3 Legislation

The EG FTF suggests the actions described here below.

The EU legislators should:

- review the Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles (2009/33/EC). This review could offer an opportunity to impose more ambitious obligations on public procurers (the Directive requires public authorities, contracting entities and operators under a public service contract to take into account vehicles' operating lifetime energy and environmental impacts when procuring road transportation vehicles). In this respect, public procurement could include cross border joint procurement as an instrument to develop the market uptake of alternative fuel transport systems. Public procurements could include a quantified percentage of alternative fuels vehicles in any public tendering to stimulate the market. Moreover, a double labelling could also be included informing of the price of vehicles, one indicating the market price and a second one taking into account the external costs as monetised in the Directive.
- consider the amendment of Directive 98/70/EC relating to the quality of petrol and diesel fuels to introduce parameters for alternative fuels that have an effect on

health and the environment, for example the sulphur content of alternative fuels to the same level as required for petrol and diesel since the mid-2000's.

- avoid addressing the same issues in two different acts, as in the case of Directive 2009/28/EC on the promotion of the use of energy from renewable sources (RED) and Directive 98/70/EC relating to the quality of petrol and diesel fuels (FQD)
- consider the feasibility to establish a stricter CO_2 target by 2030 than the target of 95 g CO_2/km as average emissions for the new car fleet established in Regulation (EC) No 443/2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles. Setting CO2 emission performance standards for heavy duty vehicles should be further assessed.
- consider to what extent external costs are already internalised in the different modes of transport and consider the effectiveness of current and potential new EU legislation in this respect. The costs of infrastructure's wear and tear, congestion, noise, and air pollution could be internalised through distance-based user charges, e.g. road tolls or track access charges in the rail sector. As regards the climate change costs, two main market-based instruments could be used: energy taxation and/or emission trading systems. These instruments would also influence the emissions caused by the inventory car fleet, taking into account that the regulation of new car emissions has only limited effect on overall emissions from the transport sector.
- consider the inclusion of hydrogen and biomethane as a clean alternative fuel via a compliance mechanism under the possible amendment of the Fuel Quality Directive
- ensure that hydrogen produced with certified renewable electricity can be accounted as 100% renewable fuel in the framework of RED directive as soon as possible
- consider complementing the list of low carbon fuel pathways or introducing a mean to produce cleaner fuels via an alternative compliance mechanism in the Council directive on laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC (FQD) relating to the quality of petrol and diesel fuels for example use of or benefits from additional hydrogen production pathways (natural gas using steam reforming with carbon capture and storage, municipal waste biogas using steam reforming, and digester biogas using steam reforming)
- introduce a methodology to measure GHG emissions from biomethane compatible with the Renewable Energy Directive. This would allow for full assessment of the performance of feedstock (wet manure, maize and bio waste calculations for other usual feedstock such as straw and alternative crops should be provided in order to facilitate the GHG calculation and its implementation also at the farm level. Moreover, the biowaste pathway should be divided into several sub-sections due to the significant differences in the GHG emissions between pure food waste, industrial wastes, sewage sludge etc.) and the relevant technologies for the production and upgrading of biogas
- ensure that the engine certification for fuels other than EN 590 be made with less administrative burden. The current requirement in the Euro VI emission regulation requires a complex certification processes a manufacturer declares his engine can operate on fuels other than, for example the test reference fuels (B7) or EN 590. Moreover, the current legislation is only considering fossil fuels references in CO2 emissions calculation; this prevents incentives for higher quality paraffinic fuels that manufacturers may wish to declare their engines may use. A review of the relevant legislation seems necessary to acknowledge the advantages of paraffinic fuels in terms of energy efficiency and pollutant emissions
- ensure that the engine certification for inland navigation and marine use, foreseen in the revision of Directive 97/68/EC will include appropriate definitions of alternative fuels, especially for gas fuelled engines

- implement the forthcoming technical requirements, which will allow the use of LNG on inland navigation vessels sailing on the Rhine, on all inland waterways of the EU by amending Directive 2006/87/EC accordingly.

Member States should:

- allow the use of renewable jet fuels in their targets to meet compliance for renewable transportation fuel consumption
- consider setting aside an increasing percentage of airport slots for flights which use a certain minimum of renewable jet-fuel, or providing a discount on air traffic management airport fees for such flights
- ensure that national regulations facilitate the access to the gas grid for CNG investors and refuelling station operators. CNG stations should be acknowledged as specific users.

7.4 Business models and incentives for the promotion of alternative fuels infrastructures and transport systems

The Group suggests the actions described here below

The EU legislators should establish a framework of policies at the EU level for fair treatment of alternative fuel vehicles and vessels and to avoid market fragmentation

The Commission and Member States should support alternative fuels production, alternative fuels transport systems and the relevant infrastructures, whilst respecting the principle of technology neutrality. In particular, support is needed to reduce risk for investors in bringing the technology to a commercial scale. In this respect the usefulness of dedicated financial instruments should be investigated, including for alternative fuels commercial vehicles. Infrastructure projects to support the build-up of alternative fuels infrastructures according to the Directive on the deployment of alternative fuels infrastructure should also be facilitated by transitional incentives and CEF - TEN-T and Structural Funds, and EIB loans

In addition to the specific technical challenges associated with the efficient use of alternative fuels on board of vessels, other issues need to be accounted for in the development of the business case, such as technical issues at port and in distribution chains, uncertainty on fuel availability and fuel prices, safety issues on board and at port, integration of new technologies on board and environmental and efficiency lifecycle considerations[122]

Member States should:

- should when establishing a range of financial and non-financial incentives to low carbon-emissions and low regulated air emission (PM, NO_X, HC and CO) vehicles in transport during the market introduction phase (e.g. bonuses for low-emission vehicles, tax exemptions for company cars, no tax on alternative fuels, reserved highway lanes, free or reduced public parking prices etc.) limit those incentives in time and value

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[122] see also Acciaro, M. and Kakalis, N. (2014). Alternative Fuels for Shipping: A Research Agenda, Annex to the European Sustainable Shipping Forum (ESSF) Sub-Group on Research and Innovation submission to the 3rd Plenary Meeting, 4 December 2014.

- consider introducing initiatives to mobilise private capital in the alternative fuel sector
- consider providing support to citizens for the purchase of home recharging/refuelling appliances in order to bridge possible infrastructure gaps
- encourage investment in different business models (e.g. car sharing) supporting the higher uptake and use of alternative infrastructure
- support investment in alternative fuels vehicles to create further confidence at infrastructure investor level.

The industry is recommended to create sustainable business models with the aim of building investor confidence in the market, reducing the early financial risks for stakeholders (alternative fuels suppliers, OEMs, alternative fuels refuelling operators). Regarding electromobility, if the impact on the electric grid of a large number of electric vehicles (including urban transport) is not asserted, smart charge management strategy and planning could optimize the use of the grid and avoid outages. This approach could also be integrated in a wider view on the business model of the sector.

7.5 Transport systems and fuel standards

The Group suggests the actions described here below.

It is recommended that more standardisation efforts are made in the ICT domain to ensure interoperability of data exchange and communication in the e-mobility ecosystem. Indeed, ICT and smart systems could be used not just for improving the energy efficiency of the electric drivetrain and the energy management but also for enhancing the use of electric infrastructures and vehicles. Common exchange of data could indeed allow drivers of electric vehicles to use new services such as routing and navigation functionalities, booking and reservation, interoperable payment systems or the integration into a multi-modal transport system and city planning. To this end, different interoperability platforms are carrying out important standardisation work to promote open standards and harmonisation of data exchange and interfaces. The work in this field needs to be continued and intensified in order to reach consensus and harmonisation at European level.

The Commission should:

- mandate to the relevant European Standardization Organizations the development of fuel quality specifications for bio-kerosene
- make sure that the next revision of the JEC WELL-TO-WHEELS study includes average values of GHG emissions for all energy sources used in transport (oil, natural gas, electricity, etc.)
- carry out an analysis on the "greenhouse gas reduction potential through the use of LNG and other alternative energy sources (fuels) in inland navigation" (CCNR 2012) to assess the potential contribution of inland navigation to GHG reduction targets.

- ensure that future EU fuel blending standards recognises the advantages of paraffinic fuels (energy efficiency of engines, and fungibility) so as to avoid any barriers to the further deployment of these fuels.

The Commission and industry should:

- continue and intensify technical and economic studies and engine tests on higher levels of blends of bioethanol in petrol (e.g. E20 and E25) while also assessing the pros & cons for the vehicle side and the fuel refining and distribution side
- continue and intensify technical studies and engine tests on levels of blends higher than 50% of bio-kerosene in kerosene for aviation.

The European Committee for Standardisation should:

- finalise the process for the adoption of the B10 and the B30 standards for liquid biofuels (this latter exclusively intended for use in captive fleets of dedicated vehicles) and carry out technical studies to ascertain the need for an E20 standard
- finalise the development of the standards for natural gas and biomethane for their use in transport and for the injection of biomethane in the natural gas and to ensure that these standards deliver natural gas and biomethane at all filling points at the level of quality that will be suitable for use in current and advanced technology gas vehicles[123]
- finalise the development of standards for LNG use on board inland and maritime vessels (fuel quality, bunker stations, connectors and couplings)
- ensure compatibility of standards to be developed under the Directive on the deployment of alternative fuels infrastructure with maritime and inland regulations developed at international and EU level
- provide guidelines and recommendations for best practices to manage new fuels, dual-fuel systems, bunkering procedures, etc.
- Finalise the future norm on synthetic fuels on the basis of [CEN prEN 15940] to ensure that standards deliver level of quality for synthetic fuel that will be suitable for use in vehicles.

7.6 **Public acceptance**

The Group suggests the actions described here below.

Member States should:

- organise promotional campaigns to encourage citizens to switch to alternative fuel vehicles
- promote actions to improve the public perception of safety of hydrogen, LNG and CNG and LPG as fuels for transport and ensure that differences are explained properly
- ensure appropriate access to information by the consumer on the location of refuelling possibilities for different fuel types.

7.7 **Research and demonstration**

There is a need to accelerate the transition of the transport system based on fossil fuels to alternative fuels.

The Group suggests the actions described here below.

On the energy side, the R&I priorities at EU and Member States levels should be the production at competitive prices of renewable electricity, hydrogen, advanced biofuels, paraffinic and non-paraffinic synthetic fuels from biomass, biomethane and bio LPG. To this end, pre-competitive production plants should be developed by the industry

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[123] See recitals (39), (41) and (63) of Directive 2014/94/EC.

with EU support with a view to switching to the very commercial phase as quickly as possible.

On the transport side, the R&I priority should be the implementation of large scale demonstration projects demonstrating the technological and environmental performance, measured in real conditions, of the different transport alternative fuel systems when significant technological development has taken place.

In particular, the focus should be on:

- Innovations for Battery and Systems Manufacturing**.** Development of a new European generation of electric batteries to increase the charge out capacity of the batteries, duration and reducing costs
- Next generation electric drivetrains, focusing on high efficiency, integration and cost
- Innovative energy storage solutions, considering system optimisation based on existing chemistries
- Electrification of L-category vehicles (considering systems integration, weight reduction, charging aspects, demonstration)
- Improving the performance of next generation FCEVs and reach the highest international levels in terms of modularity, refuelling time, reliability, safety and availability of hydrogen refuelling stations. Develop and produce Competitive European PEMFC stack for transport application
- Supporting breakthroughs technologies research and fundamental research for Fuel cell and hydrogen to develop a second generation of components and systems for fuel cells, electrolysers, hydrogen storage, new materials
- Optimisation of fuel cells components and manufacturing processes with aiming at reduction of costs. Support pilot lines for FC and H2 technologies to accelerate the industrialization processes
- Development of FCH technologies in sectors other than road, including propulsion, auxiliary power units (APUs) and shore-side electricity supply for ships; traction motors for trains on non-electrified tracks in sensitive locations (e.g. stations, suburban trains, protected areas); and APUs for aeroplanes. This would help generating critical mass for FCH technologies and accelerate their transition to mainstream solutions
- Advanced biofuels production (e.g. thermochemical pathways; biochemical pathways; microalgae harvesting, bioenergy carriers) in energy - driven bio refineries and including valorisation of bio co-products should be prioritized
- Further energy efficiency improved mono-fuel Natural Gas engines and direct injection
- Advanced biomethane production from waste and power to gas. Waste includes agricultural waste and residues (straw, manure, etc.), which have also a lot of potential as well as environmental benefits (nutrients and organic matter recycling, mitigated groundwater pollution, etc.) and can significantly contribute to reducing GHG emissions
- Further improvement of CNG and LNG storage systems
- New technological routes for processing biomass into high quality transportation fuels
- The production of synthetic fuels Sun-to-Liquid (STL) - should be reinforced. This technology appears extremely promising as it is based on the use of potentially unlimited sustainable feedstock not competing with food. At the horizon 2020/2030 it might progressively allow the production at large scale of carbon neutral synthetic

drop-in fuels, in particular kerosene, and hence reduce significantly the global CO_2 emissions from aviation and more widely from transport

- Implementation of an enlarged LNG Blue Corridors project. The next step should be the implementation of LNG as a commercial truck fuel through a technology support package for stations and vehicles, as well as a much stronger support of bigger fleets of heavy duty vehicles and delivery vans in existing transport hubs and specific areas of high demand. Create CNG Blue Corridor with the focus on light commercial vehicles and medium and heavy delivery trucks
- Research should be continued to minimise methane slipping through the combustion process, the exhaust after treatment systems, and gas tank systems
- Development of optimized internal combustion power trains matching the characteristics of the fuel with the design of the power train in order to improve the energy efficiency of vehicles
- Innovative aircraft technology, operations and infrastructure, as well as continued development and application of sustainable bio-kerosene sourcing production and distribution
- Optimisation of conventional ship engines, including fuel flexibility, new materials, lifetime performance and near zero emissions engines, and develop of standardisation in order to ease certification of such engines
- Development of LNG/dual fuel engines for small and mid-size marine ships and inland navigation vessels, including the specific aspects of retrofitting, fuel supply and storage, safety (on-board and on-shore) and classification, and solutions to address the risks of methane slip
- Further research on mitigation of methane slip on marine and inland navigation vessels. It could be useful to put in place a methane emissions observatory, which aggregates data received from emission monitoring on vessels
- Compatibility of alternative fuels with maritime use (e.g. long storage, corrosion, water infiltration, high salinity environment)
- Safety issues in handling procedures and storage (e.g. LNG IGF code, CCNR rules, tank locations, concomitant presence of multiple fuels on board, bunkering procedures)
- Classification rules development, design guidelines, recommended practices, and standardisation for inland navigation and marine alternative fuels
- Guidelines and recommendations for best practices to manage the increasing complexity of advanced ship systems
- Advanced condition monitoring technologies to ensure safe and reliable operation of new technologies on-board ships
- The development of dual / hybrid rail propulsion systems for the rail freight, sector including alternative refit and hybridisation concepts for existing areas of application, based on life-cycle costs, flexibility, safety and infrastructure requirements.

Interactions between the new oil additives such as viscosity index improvers (very trendy at the moment) and alternative fuels, which can be blends. The focus should be on the effects of these interactions on the engines of different classes as passenger car of heavy duty.

8 Existing financial mechanisms

The European Investment Bank (EIB) has already a number of different financial instruments that can support the wider market penetration of alternative transport fuels. This chapter outlines these different instruments.

8.1 The role of the European Investment Bank

The EIB, in close cooperation with the Member States and the European Commission, supports the financing of the **development** and **market introduction** of **new technologies** and **innovations**, **fostering clean** and **more sustainable mobility,** as well as the **deployment** of the **supporting infrastructure** for **alternative fuels**.

8.2 Financing of RDI and Transport infrastructure

The EIB is a major financier of **EU Transport infrastructure** (both urban and interurban) with a focus on **sustainable transport** and **trans-European transport networks**. It lends more than 10 billion Euro per year to transport related projects of European interest using various financial instruments, in conjunction with European Commission’s grants (Connecting Europe Facility, Structural and Cohesion Funds). The EIB will bring its support to the deployment of alternative fuels supply infrastructure throughout Europe, in line with the new EU Directive, by using the most appropriate financial tools, including new financial instruments.

The financial support of the EIB to **RDI**[124] - **Research, Development** and **Innovation -** for the development of clean and sustainable transport technologies will continue. This support may also include investments in pilot technological deployment programmes. For projects where the technologies are sufficiently mature but require an integrated implementation, the EIB provides funding to the deployment and the operational phases of the infrastructure, including the dedicated equipment – hardware and software - and the networks interconnectivity.

The potential beneficiaries of EIB financing can be public, private or PPP (public-private partnership) legal entities, depending on the type, the conditions and the scope of the initiatives.

8.2.1 Background - State of play

With approvals of about EUR 21 billion since 2008, the frontrunner for *the development of technologies for alternative fuels* - the automotive sector - is the largest industrial sector in the Bank's lending portfolio, and a key sector in the EIB's Growth and Employment Facility. The majority of automotive lending has been dedicated to Research, Technological Development, Demonstration and Innovation investments (RDI) projects, notably in the areas of reduction of emissions and of fuel consumption and also on safety. Alongside RDI projects, the Bank is supporting the deployment of breakthrough technologies, such as technologies and infrastructure for the roll-out of electric mobility and other alternative fuels in road transport.

More than 20% of the lending to the automotive sector has been provided under the Risk Sharing Finance Facility (RSFF), an innovative instrument developed by the EIB and jointly implemented with the European Commission to finance higher risk RDI projects, supporting Europe's automotive industry in maintaining RDI investments in

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[124] Including Fundamental Research, Industrial Research, Experimental Development, etc.

areas with longer lead times and lower profit expectations. This instrument continues since June 2014 under the **InnovFin**[125] label.

8.3 Bridging the gap. The Technical Assistance tool

While maintaining its approach of technology neutrality, the EIB continues exploring further possibilities for supporting the implementation of the different options of alternative fuels. For projects still at an early stage, the EIB offers dedicated Technical Assistance instruments, such as the ELENA[126] facility. Its objective is to support local and regional public entities to bridge the gap between first feasibility studies and final implementation, improving the investment readiness of projects targeting energy efficiency, also under mobility terms.

8.3.1 State of play

The ELENA facility supports sustainable and more energy efficient mobility solutions, which include the alternative fuels. For projects **technologically still at a preliminary level** of their development, implementation and deployment phases, the ELENA facility is meant to support the promoters on the **feasibility and pre-deployment studies**, linked to a committed leverage factor. In the field of alternative fuels, the projects[127] that have benefited from support of ELENA, did involve private and public integrated charging networks and supporting infrastructure.

8.4 Support to SMEs and MidCaps.

In addition to the EIB existing programmes128 for facilitating access to funding to SMEs and Mid-Caps, and in line with the European Commission's targets under the Horizon 2020 framework for RDI, aiming at encouraging SMEs and Mid-Caps to maintain and/or increase RDI in Europe, the EIB has investigated further which tools could improve financial terms and their access to finance. The focus is on SMEs and Mid-Caps highly R&D- intensive, innovative, with strong development prospects, and especially on companies experiencing difficulty accessing credit from commercial banks. The projects may include the development of breakthrough technologies and solutions for alternative fuels and sustainable mobility.

8.4.1 State of play

Building on the success of the Risk Sharing Finance Facility (RSFF) and recognising the need to help innovative SMEs to access bank's financing, the Commission together with the EIB launched at the end of 2011 the Risk Sharing Instrument (RSI) facility, a new facility within the RSFF managed by EIF, providing loans and leases to SMEs undertaking research, development or innovation investment projects. Further focus will be put on the innovative Mid-Caps segment under **InnovFin** label, which is the continuation of the RSFF programme since June 2014.

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[125] http://www.eu-nited.net/cms/upload/pdf/InnovFin_FAQ_FINAL.pdf.
[126] ELENA (European Local ENergy Assistance) technical assistance facility for projects on sustainable energy in towns and regions.
[127] http://www.eib.org/products/elena/index.htm.
[128] http://www.eib.org/projects/priorities/sme/ - http://www.eib.org/attachments/thematic/supporting_smes_en.pdf.

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10 Acronyms & Abbreviations used in the report

APU:	Auxiliary Power Unit
BEV:	Battery Electric Vehicle
BTL:	Biomass To Liquid
CEP:	Clean Energy Partnership
CNG:	Compressed natural Gas
CPT:	Clean Power for Transport Directive
CSP:	Concentrated Solar Power
CTL:	Coal To Liquid
DME:	Dimethyl Ether
DNI:	Direct Normal Irridiance
EBA:	European Biogas Association
ECA:	Emission Control Areas
ETS:	Emission Trading System
FCEB:	Fuel Cell Electric Busses
FCEV:	Fuel Cell Electric Vehicles
FCH:	Fuel Cell and Hydrogen
FQD:	Fuel Quality Directive
FT:	Fisher-Tropsch diesel
GHG:	Green House gas
GTL:	Gas to Liquid
HDV:	Heavy Duty Vehicles
HEFA:	Hydrogenated Ether and Fatty Acids
HRS:	Hydrogen Refuelling Stations
HVO:	Hydrotreated Vegetable Oils
IATA:	International Air Transportation Association
ICE:	Internal Combustion Engine
ILUC:	Indirect Land-Use Changes
IMO:	International Maritime Organisation
JU:	Joint Undertaking
LDV:	Light Duty Vehicles
LFL:	Low Flashpoint Fuels
LNG:	Liquefied Natural Gas
LPG:	Liquefied Petroleum Gas
MESP:	Minimum Ethanol Selling Price
MHV:	Material handling Vehicles
MJ:	Mega Joule
MMT:	Million Metric Tons
MSW:	Municipal Solid Waste
NGVA:	Natural Gas vehicle Association
OPEX:	Operating Expense
PHEV:	Plug-in Hybrid Electric Vehicle
PM:	Particulate Matter
PTL:	Power To Liquids
RED:	Renewable Energy Directive
REEV:	Range Extended Electric Vehicles
RES:	Renewable Energy Sources

TCO: Total Costs of Ownership
TOE: Ton of Oil Equivalents
TTW: Tank To Wheel
WECV: Wireless Electric Charging Vehicle
WTT: Well To Tank
WTW: Well To Wheel

Appendix A Summary of well to wheels approach

JEC (2014b) shows the energy expended and GHG emissions using a methodology split on the energy used (including energy losses) for transforming the primary energy source (fossil or renewable) into a transportation fuel (WTT) and the energy consumed and GHG amounts emitted when simulating the use of the vehicle (TTW).

The Well to Tank (WTT) evaluation accounts for the energy expended and the associated GHG emitted in the steps required to deliver the finished fuel into the on-board tank of a vehicle.

The Tank to Wheels (TTW) evaluation accounts for the energy expended and the associated GHG emitted by the vehicle/fuel combinations.

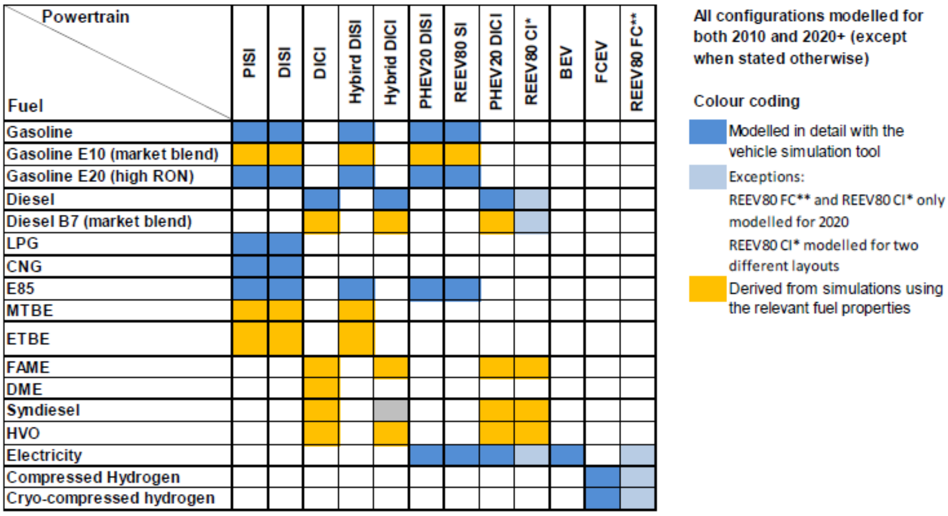
In any well-to-wheels study, there are many sources of uncertainty. A large part of the data pertains to systems or devices that do not yet exist or are only partly tested. Future pathways may include existing components that are well characterised, but also new aspects where performance figures are expectations rather than firm figures. Estimates of uncertainty are included for each individual element in a pathway and these will naturally be wider for future options that are not yet well characterised.

Table Apx A-1 The primary energy sources and the use in transportation (WTT).used in and replicated from JEC (2014b).

Resource	Fuel	Gasoline, Diesel (2010 quality)	CNG/CBG/SNG	LPG	Hydrogen (comp., liquid)	Synthetic diesel	DME	Ethanol	MT/ETBE	FAME/FAEE	HVO	Methanol	Electricity	Heat
Crude oil		X											X(5)	X(6)
Coal					X(1)	X(1)	X					X	X	
Natural gas	Piped		X		X(1)	X	X					X	X	X
	Remote		X(1)		X	X(1)	X(1)		X			X	X	X
Shale gas			X											
LPG	Remote(3)			X					X					
Biomass	Sugar beet							X						
	Wheat							X	X					
	Barley/rye							X						
	Maize (Corn)		X(2)					X(4)						
	Wheat straw							X						
	Sugar cane							X						
	Rapeseed									X	X			
	Sunflower									X	X			
	Soy beans									X	X			
	Palm fruit									X	X			
	Woody waste				X									X
	Farmed wood				X	X	X	X				X	X	X
	Waste veg oils									X	X			
	Tallow									X	X			
	Organic waste		X(2)										X	X
	Black liquor				X	X	X					X	X	
Wind			X			X							X	
Nuclear													X	
Electricity					X									

The coverage of the WTT and TTW paths are illustrated in Table 10-1 for the WTT aspects and in Table 10-2 for the use of the alternative fuels. JEC (2014b) outlines both figures at 2010 and 2020 time horizons. However, in this report only the 2010 figures are used.

Table Apx A-2: Automotive fuels and powertrain combinations used in JEC (2014b)



Powertrain / Fuel	PISI	DISI	DICI	Hybrid DISI	Hybrid DICI	PHEV20 DISI	REEV80 SI	PHEV20 DICI	REEV80 CI*	BEV	FCEV	REEV80 FC**
Gasoline	🟦	🟦		🟦		🟦	🟦					
Gasoline E10 (market blend)	🟨	🟨		🟨		🟨	🟨					
Gasoline E20 (high RON)	🟦	🟦		🟦		🟦	🟦					
Diesel			🟦		🟦			🟦	▨			
Diesel B7 (market blend)			🟨		🟨			🟨	▨			
LPG	🟦	🟦										
CNG	🟦	🟦										
E85	🟦	🟦		🟦		🟦	🟦					
MTBE	🟨	🟨		🟨								
ETBE	🟨	🟨		🟨								
FAME			🟨		🟨			🟨	🟨			
DME			🟨									
Syndiesel			🟨		▒			🟨	🟨			
HVO			🟨		🟨			🟨	🟨			
Electricity						🟦	🟦	🟦	▨	🟦		▨
Compressed Hydrogen											🟦	▨
Cryo-compressed hydrogen											🟦	▨

All configurations modelled for both 2010 and 2020+ (except when stated otherwise)

Colour coding

🟦 Modelled in detail with the vehicle simulation tool

▨ Exceptions:
REEV80 FC** and REEV80 CI* only modelled for 2020
REEV80 CI* modelled for two different layouts

🟨 Derived from simulations using the relevant fuel properties

Both the WTT calculations and the TTW calculations are built upon a number of assumptions. There are different methodological choices regarding by-products of fuels, that are relevant in understanding the production pathways and specific allocation of CO_2 emissions per main product and co-products/ by-products.

Model vehicle configuration

The TTW analysis is based on the definition of relevant parameters for a theoretical vehicle representative of the European passenger car fleet. The vehicle platform is then defined according to the specific passenger car configurations relevant for the entire range of fuel/energy/powertrain combinations and evaluated using the New European Driving Cycle to estimate energy expenditure and GHG emissions.

Vehicle simulations were carried out using the AVL CRUISE vehicle software which is a development from the ADVISOR vehicle simulation tool used in earlier versions of the WTW study.

Applicability to other vehicle configurations

The WTW analyses is focused on passenger cars. However, it is possible to generalise to e.g. HDV as well as other vehicle configurations, as also outlined in JEC (2014b) in Section 2.6. WTT data can be directly applied to any other engine and vehicle applications. However, WTW data are dependent on the specific vehicle configuration. A heavy duty WTW study would also need to include additional vehicle/fuel combinations, e.g. dual fuel concepts for CI with LNG or CNG as the main fuel.

In a qualitative manner, and with regard to the general ranking of the different fuel pathways, the results from the conventional powertrain TTW simulations (ICE) are reasonably relevant also for heavy duty.

Appendix B Different development projects in the EU

Electric transportation EU projects

- **Green eMotion project**. *(EC contribution 24.2 M€, 48 months)*. Green eMotion was a four-year EU project to promote electromobility in Europe, which was officially launched in Brussels on 31 March 2011. Green eMotion connects ongoing regional and national electromobility initiatives leveraging on the results and comparing the different technology approaches to promote the best solutions for the European market. In ten demo regions throughout Europe, 42 project partners, partners coming from industry, the energy sector, electric vehicle manufacturers, and municipalities as well as universities and research institutions joined forces to explore the basic conditions that need to be fulfilled for Europe-wide electro mobility.

  The project developed and demonstrated a commonly accepted and user-friendly framework that combined interoperable and scalable technical solutions with a sustainable business platform. For the implementation of this framework, Green eMotion took into account smart grid developments, innovative ICT solutions, different types of EVs (including plug-in and hybrid), as well as urban mobility concepts.
- **FREVUE project** *(Start date 15/03/2013, EC contribution 8 M€, 54 months)*. Eight of Europe's largest cities will demonstrate that electric vehicles operating "last mile" freight movements in urban centres can offer significant and achievable decarbonisation of the European transport system. Demonstrators will be deployed in Amsterdam, Lisbon, London, Madrid, Milan, Oslo, Rotterdam and Stockholm. The demonstrators have been designed to ensure the FREVUE covers the breadth of urban freight applications across Europe.

  By exposing 127 electric vehicles to the day-to-day rigours of the urban logistics environment, the project will prove that the current generation of large electric vans and trucks can offer a viable alternative to diesel vehicles - particularly when combined with state-of-the-art urban logistics applications, innovative logistics management software, and with well-designed local policy
- **ZeEUS project** (Start date 01/11/2013, EC contribution 13.5 M€, 42 months). The objective of ZeEUS is to demonstrate the economic, environmental and societal feasibility of electric urban bus systems. This objective will be achieved by means of different demonstrators, spread around European cities that, combining innovative technologies for electric vehicles and infrastructure, will show the capability of electric bus systems to fulfil the mobility needs of citizens in urban environments.

Hydrogen and fuel cell projects

Major national roll-out projects such as the German and UK H2 Mobility programmes are leading the way:

- **H2 Mobility in Germany**: In Sept 2013, six partners in the H2 Mobility initiative Air Liquide, Daimler, Linde, OMV, Shell and Total draw up an action plan for the construction of a nationwide infrastructure of 400 stations by 2023. The H2 Mobility initiative expects that a total investment of around EUR 350 million will be required. 16 public HRS are already operational in Germany. Another 34 stations will be subsidised by the government in the frame of the Clean Energy Partnership (CEP).
- **The Scandinavian Hydrogen Highway Partnership** in the Scandinavian countries was formed in June 2006 to build a regional infrastructure. It so far achieved the deployment of 11 stations (Denmark 3, Norway 5, Sweden 1, Iceland 1, Finland 1). In early 2011, Hyundai signed a MoU with representatives from

Sweden, Norway, Denmark and Iceland under which it will provide FCEVs for demonstration and the countries will continue to develop the infrastructure.

- In Denmark, the government's Energy Plan 2020 announced in March 2012 foresees the deployment of a countrywide infrastructure by 2015 (15 stations achieving a maximum distance of 150 km to the nearest station).
- Finland published its Hydrogen Roadmap in April 2013 confirming its potential not only for reducing carbon footprint but also to improve the country's balance of payments.
- **UKH2Mobility:** In January 2012, the UK government signed a MoU with six automotive OEMs 2 component companies, three industrial gas companies, a Utility and 2 major retailers to create UK H2 Mobility, which reviewed the specific UK case for the introduction of FCEV. The main conclusion is that 10% of new car customers (light goods vehicles and buses were not the focus) would be receptive to a FCEV option when first introduced and could be served by an initial network of 65 stations in heavily populated areas and along national trunk routes. Plan is to deploy +65 stations 2015/2017 and +300 stations 2017/2025.

  The financing of the initial stations is to be covered with 50% support by the government and 50% by the industry and the first tranche of support for new stations (and upgrades for existing stations to make them publically accessible) was announced in November 2014. The UK government will also support FCEV introduction under the Ultra Low Emission Vehicle rebate scheme. Hydrogen Mobility in France: In July 2013, the Mobilité Hydrogène France consortium launched with twenty members including gas production and storage companies, energy utilities and government departments. The group is cofounded by the consortium partners and the HIT project (TEN-T project of EUR 3.5 million launched in January 2013 to form an interconnected hydrogen network between the Netherlands, Denmark, Sweden and France). The group is carving a plan for the deployment of infrastructure over 2015-2030. . Special attention is drawn on the importance of Hydrogen fuelled Light Duty Vehicles for fleet operators to start introducing the technology. The deployment strategy for hydrogen infrastructure is quite different from the other countries and based on range Extender approach and captive fleet deployment as early market, despite captive fleet represents a large part of the car market (40%). This approach described above allows to decrease the investment risk and to reach a positive business model earlier than classical massive HRS deployment.

- The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is the European public-private partnership that supports the research, development and demonstration towards commercial introduction of fuel cells and hydrogen technologies through annual calls. Under 7th Framework Programme it had a budget of nearly EUR 1 billion from 2008 to 2013, of which the private sector contributed 50%. The follow up of the programme under Horizon 2020 was launched in July 2014. Bringing together public and private resources, the partnership will invest at least EUR 1.3 billion to implement an optimal research and innovation programme at EU level to develop a portfolio of clean, efficient and affordable fuel cell and hydrogen solutions. The second FCH JU programme will focus on bringing the technology to the point of market readiness and addressing key bottlenecks towards mass market deployment.

Biofuels for aviation projects

In June 2011, the European Commission (DG Energy) launched the initiative ‘The **European Advanced Biofuels Flight Path**’ in close coordination with Airbus, leading European airlines (Lufthansa, Air France/KLM and British Airways) and European biofuel producers (Neste Oils, Biomass Technology Group, UPM, Chemtex Italia and UOP) to achieve an annual production of 2 million tonnes of sustainably produced biofuel for aviation by 2020.

ITAKA

Initiative Towards sustAinable Kerosene for Aviation (ITAKA) is a collaborative project framed in the implementation of the European Industrial Bioenergy Initiative (EIBI) and specifically aims to contribute to the fulfilment of some of the short-term (2015) EU Flight Path objectives. The ITAKA project is designed to support the development of aviation biofuels in an economically, socially, and environmentally sustainable manner, improving the readiness of existing technology and infrastructures. This will be achieved through a first of its kind collaborative project in the EU, which has started the development of a full value-chain in Europe to produce sustainable drop-in Hydroprocessed Esters and Fatty Acids and Synthetic Paraffinic Kerosene (SPK) at large scale. ITAKA targets camelina oil as the best possible sustainable feedstock that can be produced timely at enough quantity within Europe.

The main goal is to demonstrate the value chain by testing the use of the biojet fuel produced in existing logistic systems and in normal flight operations in the EU. It also links supply and demand by establishing a relationship between feedstock grower, biofuel producer, distributor and final user (airlines), encompassing the entire supply chain. The generated knowledge will aim to identify and address barriers to innovation and commercial deployment. Beyond these technological and research objectives, ITAKA aims at contributing to the achievement of a further EU objective: the need to coordinate efforts and complementarities among European initiatives on sustainable aviation fuels, as highlighted during the Flight Path definition.

CORE-Jet Fuel

CORE-Jet Fuel is a Coordinating Action funded under the FP7 aimed to set up a European network of excellence for alternative fuels in aviation to bring together technical expertise and provide an integrated approach to alternative aviation fuels including regulatory aspects, research, deployment and economics. It will also link initiatives and projects at the EU and Member State level in the field of alternative fuels for aviation, serving as a focal point in this area to all public and private stakeholders involved in alternative fuels for aviation, such as competent authorities, research institutions, feedstock and fuel producers, distributors, aircraft and engine manufactures, airlines and NGOs.

Appendix C Current taxing and blending schemes for biofuels

The table below is a compilation prepared by UPEI and complemented with information from RES LEGAL Europe[129]. The table summarises the different tax support schemes and quotas or mandatory blending rules for biofuels in the European countries. The level of details provided by UPEI differs between countries. Hence, e.g. "yes" indicates that a scheme or quota exists, but it has not been specified what the scheme or quota is. For some countries the specific taxes have been provided by UPEI, but this is not the case in all situations. The table only repeats the information given in the original UPEI input. It demonstrates the complexity of the environment within which biofuels suppliers operate and the lack of harmonisation in approach between Member States which creates barriers to trade, in particular for the cross border supply of biofuels (other than first generation), thus limiting the full market penetration potential of biofuels.

Table Apx C-1: A summary of tax supporting schemes and quotas in European countries. Source: UPEI and RES LEGAL Europe. Note: n.s.: no schemes

	Tax advantage		**Mandatory blending**
Country	**Biodiesel**	**Bioethanol**	
Austria	From a minimum content of 6.6 % of biogenic material are subject to a lower mineral oil tax. Mineral oil solely from biogenic material and E85 are exempt from this tax.	From a minimum content of 4.6 % of biogenic material are subject to a lower mineral oil tax. Mineral oil solely from biogenic material and E85 are exempt from this tax.	To ensure that biofuels make up a defined percentage of the annual fuel sales, there is a substitution obligation in force since 2005. From 2009, the substitution target amounts to 5.75 %, measured by the total fossil petrol or diesel introduced or used in the federal territory.
Belgium	No more tax incentives since 1.6.2014. New government proposal to the EU: from 1.1.2015, to introduce a tax incentive of €17,2/m3 of end product if 7% tendered FAME, UCO or TME is blended. 45% of the market is liberalised (therefore only 55% of the needed volume for detaxation will be tendered). There is still no approval from the EU.	No more tax incentives since 1.6.2014. New government proposal to the EU: from 1.1.2015, to introduce a tax incentive of €15,3/m3 of end product if 5% or €30,6 if 10% tendered bio ethanol is blended. 35% of the market is liberalised (therefore only 65% of the needed volume for detaxation will be tendered). There is still no approval from the EU.	Mandatory blending is regulated by the formula: «max specification in standard - 1%». Diesel: 7% -1%=6%; E5: 5% -1%=4%; E10: 10% -1%=9%. E10 is not on the Belgian market, yet. All biofuels must be proven sustainable and entered into a Belgian database which will determine its sustainability.
Bulgaria	A reduced rate of excise duty is applied to unleaded petrol or gas oil if a share of more than 4 % of bioethanol or biodiesel has been added	A reduced rate of excise duty is applied to unleaded petrol or gas oil if a share of more than 4 % of bioethanol or biodiesel has been added	Persons introducing liquid fuels of crude oil origin for transportation shall be obliged to offer market fuels for diesel and petrol engines blended with biofuels.

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[129] http://www.res-legal.eu/home/

	Tax advantage		**Mandatory blending**
Country	**Biodiesel**	**Bioethanol**	
Croatia	No tax incentives. Pure biodiesel, B100, has 100% tax incentive (excise duty = 0).	n.s	sets the % share of biofuels on the fuel market for each year up to the year 2020 as defined in the national goals
Cyprus	n.s.	n.s	n.s.
Czech Republic	No tax incentives for mandatory blended products, blend ›31% FAME has an advantage of 31% of basic excise duty 100% FAME has 100% tax incentive (excise duty = 0).	No tax incentives for obligatory blending, E85: no tax on ethanol share, full tax on gasoline share.	Yes (in % of total on market placed volume)
Denmark	Biofuels are supported through tax incentives. Moreover selling of biogas for transport purposes is supported though a direct premium tariff.	Biofuels are supported through tax incentives. Moreover selling of biogas for transport purposes is supported though a direct premium tariff.	Companies importing or producing petrol, gas or diesel fuels are obliged to ensure that biofuels make up a defined percentage of the company's total annual fuel sales.
Estonia	None	None	None
Finland	Taxation of liquid fuels is carried out as taxation of separate fuel components based on their energy content and carbon dioxide emission, meaning reduced taxation for biofuels.	Taxation of liquid fuels is carried out as taxation of separate fuel components based on their energy content and carbon dioxide emission, meaning reduced taxation for biofuels.	The main scheme used to support renewable energies in the transport sector is a quota obligation. This mechanism obliges companies selling petrol or diesel fuels to ensure that biofuels compose a defined percentage of the company's total annual sale of fuel.
France	2013: 8 €/hl 2014: 4.5 €/hl 2015: 3 €/hl 2016: 0	2013: 14 €/hl 2014: 8.25 €/hl 2015: 7 €/hl 2016: 0	n.s.
Germany	From 2013: 2.14 ct/l / no tax advantage on blend	E 85: 100% for ethanol part/no tax advantage on blend	yes.
Greece	n.s.	n.s	Obligation for producers and distributors of petrol and diesel to blend their fuels with a certain amount "quota" of biofuels.
Hungary	Diesel must contain minimum 4.4% energy content bio additive (FAME), no tax advantage on bio part.	Gasolines must contain minimum 3.1% energy content (ethanol), no tax advantage on bio part. E85 is freely available in Hungary, there is tax advantage, but the tax of E85 has been increased year by year.	Yes.
Ireland	No tax incentives	No tax incentives	n.s.

	Tax advantage		Mandatory blending
Country	**Biodiesel**	**Bioethanol**	
Italy	No tax incentives	No tax incentives	Biodiesel: blending up to 7% in retail market. Blending with 25% for the wholesale market. Bioethanol (ETBE): blending up to 10% in retail market. Blending with 25% for the wholesale market.
Latvia	No tax incentive up to 30% RME content. RME content 30-99% - tax incentive approximately 30% from original excise. 100% bio - 100% tax incentive.	No tax incentive up to 70% Bioethanol content. Bioethanol content 70-85% - tax incentive approximately 70% from original excise.	Yes.
Lithuania	Part of the price of rapeseed oil used for the production of rapeseed methyl (ethyl) ester (RME) and part of the price of rapeseed and cereal grain purchased for the production of dehydrated ethanol will be repaid. Excise tax relief applies to biofuels for transport. The rate of excise tax is reduced in proportion to the percentage of biomass per tonne of biofuel. The relief applies to bioethanol, biodiesel, bio-ETBE and vegetable oil.	Part of the price of rapeseed oil used for the production of rapeseed methyl (ethyl) ester (RME) and part of the price of rapeseed and cereal grain purchased for the production of dehydrated ethanol will be repaid. Excise tax relief applies to biofuels for transport. The rate of excise tax is reduced in proportion to the percentage of biomass per tonne of biofuel. The relief applies to bioethanol, biodiesel, bio-ETBE and vegetable oil.	n.s.
Luxemburg	No tax incentives	No tax incentives	Oil companies releasing petrol and diesel for consumption are obliged to fulfil a defined quota of biofuels per year.
Malta	Biomass content in biodiesel is exempt from the payment of excise duty	Biomass content in biodiesel is exempt from the payment of excise duty	n.s.
Norway	n.a.	n.a.	n.s.
Poland	No tax incentives	No tax incentives	No. The regulations indicate only the maximum percentage of biocomponents and not the minimum. Indirectly the companies are obliged to blend, otherwise they would not reach the mandatory National Index Target.

	Tax advantage		**Mandatory blending**
Country	**Biodiesel**	**Bioethanol**	
Portugal	Small producers of biofuels benefit from a total exemption of the Petrol Product Tax (ISP).	Small producers of biofuels benefit from a total exemption of the Petrol Product Tax (ISP).	Companies supplying fuels for consumption shall incorporate a certain percentage of biofuels in the fuels they supply to the market from 2011 to 2020.
Romania	n.s.	n.s.	there is a target for biofuels in place for adding biofuels to petrol and diesel. Only certified biofuels satisfying specific sustainability criteria can be taken into account for fulfilling the prescribed quota. Furthermore, fuel retailers are required to reduce the greenhouse gas emissions of the market fuels.
Slovakia	100% until 5 vol-% blend.	100% until 7.05 vol-% blend of ETBE	Yes
Slovenia	Transport fuels in their pure form are exempt from excise duty. Blends of biofuels with fossil fuels may qualify for a refund of excise duty paid or for an exemption from excise duty commensurate with the proportion of biofuel added, up to a maximum of 5%.	Transport fuel in their pure form are exempt from excise duty. Blends of biofuels with fossil fuels may qualify for a refund of excise duty paid or for an exemption from excise duty commensurate with the proportion of biofuel added, up to a maximum of 5%.	No for each litre / yes for year quantity.
Spain	No tax incentives since 1 January 2013. New advantages could be considered for labelled blends.	No tax incentives since 1 January 2013. New advantages could be considered for labelled blends.	Compulsory annual targets since 2009.
Sweden	Companies supplying, importing and producing fossil fuels are obliged to pay energy and carbon dioxide taxes. Biofuels are exempt from these taxes.	Companies supplying, importing and producing fossil fuels are obliged to pay energy and carbon dioxide taxes. Biofuels are exempt from these taxes.	n.s.
Switzerland	0%	0%	n.s.
The Netherlands	No tax incentives	No tax incentives	No
United Kingdom	20p/litre duty derogation on UCOME expired 31.3.2012	n.s.	n.s.

Appendix D Vehicle models offered at the European market

In this appendix a list of the different OEM vehicle models and their CO_2 emissions per km are listed. The vehicles are organised according the alternative fuels. Most conventional vehicles can use biofuels as blend in fuels. Hence, these vehicles are not included. Moreover it is not always that the same information exists across different fuels.

Electric vehicles and plug-in hybrid electric vehicles

Table Apx D-1 Vehicles that are introduced in the EU car market (source: Eurelectric, 2015).

Model	Range in electric drive (km)	Kwh/km	Estimated costs (Euro)
BMW i3	160	0.22	28,979
BMW i3 with range extender		0.22	32,690
BYD e6	250		45,368
Chevrolet Volt	64	0.22	44,525
Citroen Berlingo	170		
Citroen C-zero	150		25,247
Fiat 500e	140	0.18	23,820
Ford Focus Electric	162	0.18	35,725
Honda Fit-EV	198	0.21	28,061
Mercedes Vito e-cell	130		
Mercedes Vito e-cell minivan	130		
Mitsubishi IMIEV	145	0.19	30,950
Nissan e-NV200	170		
Nissan LEAF	198	0.12	29,900
Peugeot Ion	150		30,190
Peugeot Partner	170		
Renault Fluence	185	0.20	22,416
Renault Kangoo ZE	171	0.27	20,450
Renault Twizy	100		7,240
Renault Zoe	210	0.15	17,561
Smart for two Electric Drive	109	0.20	23,300
Smith Electric Vehicles Edison	90 - 180		
Tesla Model S (40 kwh)	257	0.20	37,425
Tesla Model S (60 kwh)	370	0.22	52,425
Tesla Model S (85 kwh)	482	0.24	59,925
Toyota RAV E4	161		37,350
VW E-Golf	130	0.22	35,500
VW E-Up	130		26,890

Fuel Cell Vehicles

Table Apx D-2 OEM manufactured FCEVs

Producer & Vehicle	Key specifications	Availability - cost
Daimler **- B-Class F-CELL** **First released 2009/2010 Vehicles currently running in Germany, Norway, California**	Mercedes Benz B-Class F-CELL 100 kW Peak Output 70 kW Continuous Output 1,4 kWh Lithium-ion battery 380 km range (NEDC) 3.7 kg H2 storage	About 200 Mercedes Benz B-Class F-CELLs are operated in customer hand in Germany, Norway and California. The vehicles are leased to the customer on a monthly leasing rate.
Honda **- FCX Clarity** **- FCX Concept launched in December 2014 and due to go into production in November 2015**		The FCX Clarity has been on (selective) lease to private drivers in California since 2009 First sales to be made in Japan in March 2016 followed by sales in California and Europe (UK, Germany, Scandinavia)
Hyundai: **- ix35 Europe** **- Tucson USA** **Production: up to 5,000 pa** **First released 2013. Vehicles currently running in Europe (Germany, Belgium, Denmark, Norway, UK), South Korea and California**	Small SUV 100kW fuel cell & 60AH battery 365mile (584km) range 5.6kg H2 storage	USA – California: lease only at \$499/month plus taxes for 36 months, inclusive of fuel and maintenance Europe – UK purchase at £53,105 inclusive of UK specific purchase support for ULEVs. Lease option also available
Toyota **- Mirai** **Production: 3,000 pa** **First released 2014. Vehicles being deployed in Japan, Europe (UK, Germany, Denmark) and California**	Executive 4 door saloon car (similar to Lexus GS300 size and spec.) 114kW fuel cell & 16.5AH battery 300mile (483km) range 5kg H2 storage	USA – California: Purchase cost at \$58,325 plus taxes or lease at \$499 per month with \$3,649 initial deposit. Europe – based on 66,000 Euro plus local taxes. Equivalent to £63,104 in the UK, before purchase support (£5,000) under the ULEV scheme. Japan – sales began on 15 December 2014 at a price of ¥6.7 million (~US\$57,400) before a subsidy of ¥2 million (~US\$19,600).[

Natural gas and biomethane vehicles

In the two tables OEM manufactured CNG passenger cars, light and heavy duty vehicles and busses are shown (Source: NGVA, 2015).

Table Apx D-3: CNG Passenger cars and light duty vehicles (vans). Source NVGA (2015)

Model	**Range (on CNG)**	**Fuel Consumption per 100 km (kg)**	**kW (HP)**	**Estimated costs incl. VAT* (Euro)**
Audi A3 Sportback g-tron	420	3.3	81 (110)	26,450
Fiat 500 L Living, CNG	359	3.9	59 (80)	21,950
Fiat 500 L Natural Power	359	3.9	59 (80)	20,950
Fiat Panda Natural Power	387	3.1	59 (80)	15,400
Fiat Punto Evo Natural Power	310	4.2	51 (70)	17,190
Fiat Qubo Natural Power	307	4.3	51 (70)	18,350
Lancia Ypsilon ecochic CNG	387	3.1	59 (80)	16,650
Mercedes-Benz B 200 NGD	500	4.3	115 (156)	32,903
Mercedes-Benz E 200 NGD	450	4.3	115 (156)	40,600
Opel Zafira Tourer 1.6 CNG Turbo	530	4.7	110 (150)	26,500
Peugeot Ion	380	2.9		12,160
Seat Leon ST TGI	420	3.5	81 (110)	22,240
Seat Leon TGI	420	3.5	81 (110)	17,310
Skoda Citigo G-tec	380	2.9	50 (68)	12,640
Skoda Octavia G-tec (estate)	420	4.5	81 (110)	22,490
Skoda Octavia G-tec (saloon)	420	3.5	81 (110)	21,850
Volkswagen eco up!	380	2.9	50 (68)	12,950
Volkswagen Golf TGI (estate)	430	3.5	81 (110)	23,850
Volkswagen Golf TGI (saloon)	420	3.5	81 (110)	23,825
Volkswagen load up!	380	2.9	50 (68)	13,950
Volkswagen Touran TGI	500	4.7	n.a.	23,100
Volvo V60 bi-fuel (delayed OEM)	370	4.3	180 (245)	36,874
Volvo V70 bi-fuel (delayed OEM)	400	4.5	180 (245)	38,707
	Vans			
Fiat Ducato Natural Power	410	8.9	100 (136)	32,500
Fiat Doblò cargo Natural Power (+ long version)	330-460	4.9	88 (120)	21,896 / 23,740
Fiat Fiorino cargo Natural Power	300	4.3	51 (70)	15,886
Fiat Fiorino Natural Power	300	4.3	51 (70)	17,195
Iveco Daily Natural Power	440	8.9	100 (136)	n.a.
Opel Combo 1.4 CNG Turbo	325	4.9	88 (120)	23,365
Opel Combo 1.4 CNG Turbo cargo	455	4.9	88 (120)	22,895
Mercedes-Benz Sprinter NGD (long version)	378-475	8.2	115 (156)	45,981
Volkswagen Caddy Maxi TGI	925	4.1	81 (110)	24,966
Volkswagen Caddy TGI	650	4.1	81 (110	23,023

* Comparison of list prices refers to Germany, as the biggest vehicle market and may differ on a national basis.

n.a. Information not available

Table Apx D-4: CNG (and LNG) heavy duty vehicles (Trucks and busses). Source: NVGA (2015)

Model	**Fuel tank capacity (kg)**	**kW (hp)**	**Estimated costs incl. VAT* (Euro)**
Iveco Stralis Hi Road CNG	198	243 (330)	n.a
Iveco Stralis Hi Road LNG	185	243 (330)	n.a.
Mercedes-Benz Econic, CNG	400	222 (302)	n.a.
Mercedes-Benz Citaro Bus CNG	90 / 105	n.a.	n.a
Scania P 280 CNG	100 /130	205 (280)	n.a.
Scania P 340 CNG	100 /130	250 (340)	n.a.
Scania P 280 LNG	190 / 310	205 (280)	n.a.
Scania P 340 LNG	190 / 310	250 (340)	n.a.
Renault D Wide CNG	90-120	235 (320)	n.a.
Volvo FE CNG	90- 120	235 (320)	n.a.
Busses			
Iveco Crossway CNG	n.a.	n.a.	n.a.
Iveco Urbanway CNG	200-230	213-243 (290-330)	n.a.
MAN Lion`s city CNG	188-247	200-228 (272-310)	n.a.
Scania Citywide LE/LF CNG	195-275	206 (280) or 235 (320)	n.a.
Solaris Urbino CNG	205-274	235 (320)	n.a.
Solbus Solcity LNG	365	235 (320)	n.a.
Van Hool A 330 / A 360 CNG (+ hybrid tram-bus)	n.a.	n.a.	n.a.
Vectia Tempus/Veris CNG (+ hybrid option)	n.a.	180 (240)	n.a.

LPG vehicles

In the table OEM manufactures LPG vehicles are shown (Source: AEPGL, 2015). Information on range not provided.

Table 10-1: LPG OEM vehicles offered to the EU market. Note that some vehicles may not be commercially present and available in all EU countries for various reasons. Source: AEPGL (2015)

Marke/Modell	Displ.	hp/kW	Fuel consumption	list price in €
Alfa Romeo Giulietta 1.4 GPL Turbo	1.4	120/88	n.a.	24.450,-
Alfa Romeo MiTo 1.4 GPL Turbo	1.4	120/88	n.a.	20.600,-
Chevrolet Aveo 1.2 GPL	1.2	86/63	n.a.	14.408,-
Chevrolet Cruze 1.8 GPL MT5LT	1.8	141/104	n.a.	20.109,-
Chevrolet Cruze LT 1.8 GPL	1.8	141/104	n.a.	19.520,-
Chevrolet Orlando 1.8 GPL LT Crossover	1.8	141/104	n.a.	23.507,-
Chevrolet Spark 1.0 LS GPL	1.0	68/50	n.a.	11.474,-
Chevrolet Spark 1.2 LT Z GPL	1.2	81/60	n.a.	14.081,-
Citroen C3 1.4 VT GPL	1.4	69/51	n.a.	18.400,-
Citroen C3 Picasso 1.4 VTi GPL	1.4	91/67	n.a.	19.650,-
Citroen DS3 1.4 VT GPL	1.4	91/67	n.a.	17.850,-
Dacia Dokker 1.6 GPL	1.6	80/59	n.a.	11.900,-
Dacia Dokker 1.6 GPL Van	1.6	80/59	n.a.	9.577,-
Dacia Duster 1.6 GPL	1.6	102/74	n.a.	13.550,-
Dacia Lodgy 1.6 GPL	1.6	80/59	n.a.	12.000,-
Dacia Logan MCV 1.2 GPL	1.2	75/55	n.a.	10.500,-
Dacia Sandero 1.2 GPL	1.1	72/53	n.a.	9.500,-
Fiat 500 1.2 GPL	1.2	69/51	n.a.	14.100,-
Fiat 500 L GPL	1.4	88/63	n.a.	20.450,-
Fiat 500 Trecking GPL	1.4	120/88	n.a.	23.310,-
Fiat Altea XL 1.6 BiFuel	1.6	98/72	n.a.	21.460,-
Fiat Panda 1.2 GPL	1.2	69/51	n.a.	12.610,-
Fiat Picanto 1.0 GPL	1.0	68/50	n.a.	11.300,-
Fiat Punto 1.4 GPL	1.4	77/57	n.a.	16.960,-
Ford B-Max 1.4 GPL	1.4	90/66	n.a.	18.250,-
Ford C-Max 1.6 GPL	1.6	120/88	n.a.	21.000,-
Ford Fiesta 1.4 GPL	1.4	92/68	n.a.	14.500,-
Ford Focus 1.6 GPL	1.6	120/88	n.a.	20.250,-
Hyundai I30 1.4 MPI	1.4	97/71	n.a.	20.600,-
Hyundai Ix20 1.4 MPI	1.4	88/64	n.a.	17.250,-
Hyundai Ix20 1.6 MPI	1.6	121/89	n.a.	19.000,-
Kia Cee‘d 1.4 GPL	1.4	98/72	n.a.	18.500,-
Kia Rio 1.2 GPL	1.2	83/61	n.a.	13.150,-
Kia Sportage 1.6 ECO GPL	1.6	135/99	n.a.	22.750,-
Kia Venga 1.4 GPL	1.4	90/66	n.a.	17.200,-
Lancia Delta 1.4 GPL	1.4	120/88	n.a.	22.950,-
Lancia Ypsilon 1.2 GPL	1.2	69/51	n.a.	14.700,-
Mitsubishi ASX 1.6 GPL BiFuel	1.6	116/85	n.a.	21.100,-
Mitsubitsi SpaceStar 1.0 ClearTee GPL	1.0	69/51	n.a.	13.050,-
Nissan Juke 1.6 GPL	1.6	117/86	n.a.	18.650,-
Nissan Note 1.2 GPL	1.2	77/56	n.a.	14.900,-
Opel Astra 1.4 Turbo GPL	1.4	140/103	n.a.	21.000,-
Opel Astra ST 1.4 Turbo GPL Estate	1.4	140/103	n.a.	23.100,-
Opel Meriva 1.4 Elective GPL	1.4	120/88	n.a.	20.620,-
Opel Mokka 1.4 GPL	1.4	140/103	n.a.	23.720,-
Opel Zafira Tourer 1.4 Turbo	1.4	140/103	n.a.	27.200,-

Marke/Modell	Displ.	hp/kW	Fuel consumption	list price in €
Peugeot 208 1.4 GPL	1.4	95/70	n.a.	14.200,-
Renault Clio 1.2 GPL	1.1	75/55	n.a.	15.100,-
Seat Nuova Ibiza 1.6 BiFuel GPL	1.6	81/60	n.a.	15.780,-
Subaro Forester 2.0i 6MT BiFuel 4x4	2.0	148/109	n.a.	32.280,-
Subaro XV 1.6i 5MT BiFuel Free crossover 4x4	1.6	114/84	n.a.	22.030,-
Subaro XV 2.0i ES BiFuel Style crossover 4x4	2.0	150/110	n.a.	28.030,-
Tata Vista 1.4 Safi re BiFuel GPL	1.4	75/55	n.a.	10.810,-
VW Caddy 1.6 BiFuel*	1.6	98/72	n.a.	24.141,-
VWCaddy 1.6 BiFuel Maxi*	1.6	98/71	n.a.	24.856,-

* According to VW these vehicles will not be available as LPG versions in the new version of the vehicle for 2015
