STRIA – Alternative Fuels

Authors: Ausilio Bauen, Inmaculada Gomez, Dave OudeNijeweme, Maria Paraschiv
2016-09-21

Contents

1 Introduction

1.1 Context for the STRIAs

On 25 February 2015 the European Commission published the Communication "A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy" setting a framework for achieving the 2030 EU climate and energy goals[1]. The Energy Union vision provides the framework to respond to the energy challenges. It is built on a set of climate and energy targets to be realised by 2030: at least 40% domestic reduction of greenhouse gas emissions, at least 27% share of renewable energy consumed in the EU and at least 27% improvement in energy efficiency. Reaching and exceeding these intermediary objectives will allow the EU to pursue the goal of an 80-95% decrease in greenhouse gas emissions by 2050.

The "Research, innovation and competitiveness" dimension of the Communication foresees the launch of 3 initiatives: the integrated Strategic Energy Technology Plan (SET Plan), the Strategic Transport Research and Innovation Agenda (STRIA) and Global Technology and Innovation Leadership Initiative.

The STRIA will contribute to the realisation of the Energy Union vision by identifying the contribution that the transport sector can make to the achievement of the climate and energy goals and providing input for research and innovation policy to maximise the impact of low-carbon technology solutions. The exercise is carried out jointly by RTD/H and MOVE/C, and will feed into the Communication on the R&I and competitiveness component of the Energy Union in November 2016. STRIAs will be developed for 7 key transport innovation areas: Electromobility, Alternative fuels, Vehicle design and manufacturing, Connectivity and automation of transport, Transport infrastructure, Network and traffic management systems, Smart transport and mobility services (incl. urban). The STRIAs identify R&I that will speed up technological changes in transport and better target public and private investments in the transport sector to tackle technical and non-technical challenges to meeting energy and climate objectives of the Energy Union and beyond to 2050.

The recent European Communication of 20 July 2016 on "A European Strategy for Low-Emission Mobility" also stresses the need to develop and deploy alternative low carbon energy options in transport, including gaseous and liquid fuels, and the need for research and innovation that brings together three interconnected strands: energy technologies, transport and industry, through an Integrated Research, Innovation and Competitiveness Strategy for the Energy Union.

1.2 Transport energy and alternative fuels use

In 2014 the EU 28 transport sector consumed 353 Mtoe, which accounted for 33% of total energy consumption (Figure 1). This figure does not include the fuel stored in maritime bunkers in Europe, which would bring the total energy consumed to 398 Mtoe. Out of this amount, the largest consumer is road traffic (73.7%), followed by aviation (12.6%), maritime (10.6%), rail (1.6%) and inland navigation (1.1%) (shown in Figure 2 and Figure 3). Oil products supplied 94% of the energy demand from transport, 86% of which was imported from outside the EU.

[1] Com (2015) 80 final

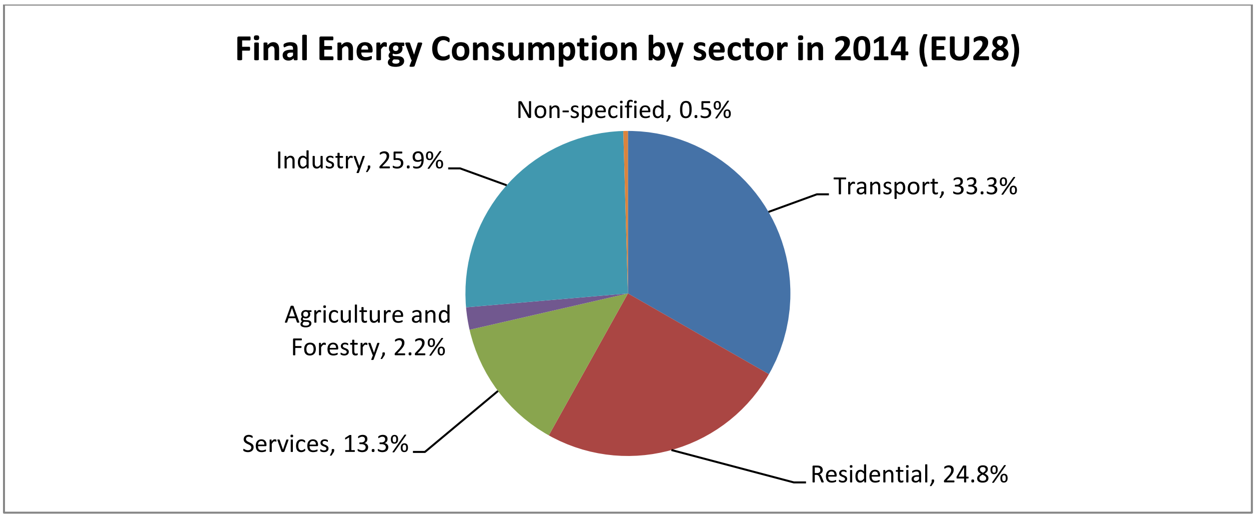

Figure 1 - Final Energy Consumption by sector (EU28). Source: Eurostat

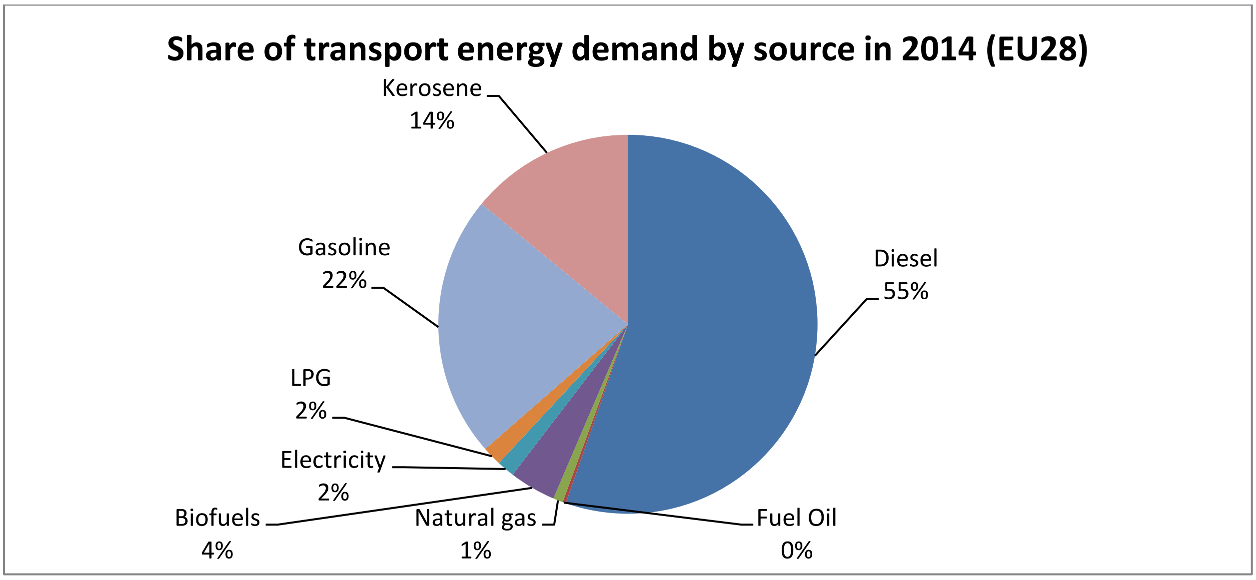

Figure 2 - Share of transport energy demand by source in 2012 (EU28). Source: Eurostat

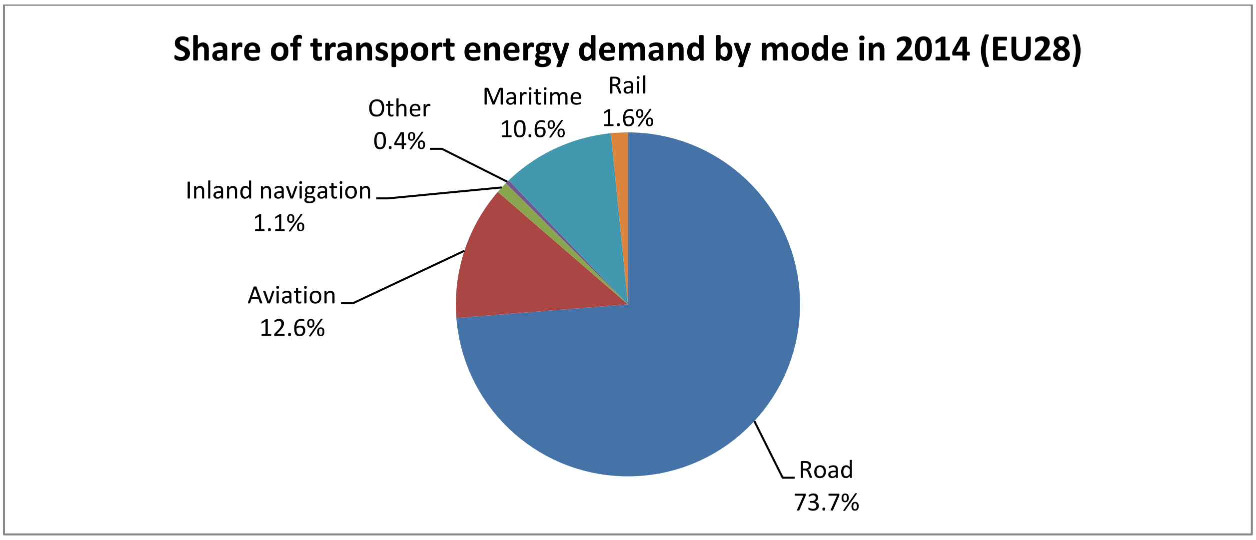

Figure 3 - Share of transport energy demand by mode in 2012 (EU28). Source: Eurostat

The transport mode that is proportionally least dependent on fossil fuels is rail, with petroleum-based products accounting for 33% of energy consumption. The dominant alternative is electricity, with some biofuel consumption in the form of biodiesel.

Road transport depended on oil products for 94% of its energy use in 2014. Alternatives include biofuels, electricity, and fossil fuels such as CNG, LNG, LPG and GTL, only some of which have some decarbonisation potential. On a total cost of ownership basis (including subsidies), in some countries BEVs and PHEVs can already be more attractive than the incumbent internal combustion enginevehicle due to lower fuel cost and taxes, and purchase incentives.

Petroleum-based products satisfied almost all of the energy demand in waterborne and air transport in 2014. Air transport is most dependent on oil, with the main alternative energy source being biofuels. Alternatives in waterborne transport are very similar to those for long range heavy duty road transport.

Transport greenhouse gas emissions, including from international aviation and maritime transport, increased by around 34% between 1990 and 2008. Over the same period, energy industries reduced their emissions by about 9%. Following the emission decline between 2008 and 2013 transport emission level in 2013 are 19,4% above 1990 levels2. The sector has been inherently difficult to decarbonise, and improvements in energy efficiency have been offset by increasing transport volumes and distances, while the take up of alternative fuels has so far been limited. Unless decisive action is taken, this trend is likely to continue and by 2030 transport is expected to become the main source of GHG emissions, surpassing the power sector[3]. This is largely due to the continued reliance of all transport modes on oil[4]. Based on current trends[5], oil products are expected to cover 88% of the EU transport energy needs in 2030 and 84% in 2050. Despite EU policies[6] and related national support schemes intended to promote a wide range of renewable and low carbon energy sources in transport, only 6% of the energy used in transport was from renewable sources in 2014[7].

Air quality also remains an issue for all transport modes (emissions from road vehicles, diesel locomotives, planes in airports and ships in harbours). As an illustration, it is estimated that one third of the EU citizens live in urban areas with pollution levels above legal thresholds and around 400,000 premature deaths every year can be attributed to pollution, where road transport is one the main contributors[8] (40%).

The 2011 EC White Paper on Transport[9] requires a 60% reduction in transport GHG emissions by 2050 (compared to 2005 levels), with specific targets for different transport modes, while at the same time drastically reducing other negative impacts (accidents, emissions/noise, congestion) and achieving

---

[2] EEA, Greenhouse gas emissions from transport. Available at: http://www.eea.europa.eu/downloads/601c247f67b243478cdf5d8531ad2630/1468931809/transport-emissions-of-greenhouse-gases-5.pdf

[3] EU energy, transport and GHG emissions. Trends to 2050 (link)

[4] 94% of energy used in transport consists in oil products, 90% of which imported

[5] State of the Art on Alternative Fuels Transport Systems in the European Union (link)

[6] Renewable energy directive (RED) and fuel quality directive (FQD). The RED mandates the use of 10% of renewable sources in transport to be achieved by 2020. The FQD introduces a 6% carbon intensity reduction target to be reached by 2020.

[7] EU energy, transport and GHG emissions. Trends to 2050 (link)

[8] European Environmental Agency: Air quality in Europe — 2014 report

[9] EC White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. Available at: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52011DC0144

sustainable mobility services for citizens and transport services for businesses. The COP21 agreement is likely to require even greater reductions, up to 100% decarbonisation by 2050 for the 1.5° scenario. Achieving deep GHG emissions savings and other energy and environment improvements in the transport sector will require a holistic approach that tackles demand for transport services, more efficient technologies and alternative fuels.

1.3 The case for alternative fuels in transport

The International Energy Agency's scenarios in its World Energy Outlook[10] and Energy Technologies Perspectives[11] publications illustrate the importance of alternative fuels in achieving GHG emissions savings in transport, in conjunction with demand and efficiency measures (Figure 4). An important feature of the scenarios is the potential relative and absolute increase in importance of road, air passenger travel and sea freight energy demand (Figure 5).

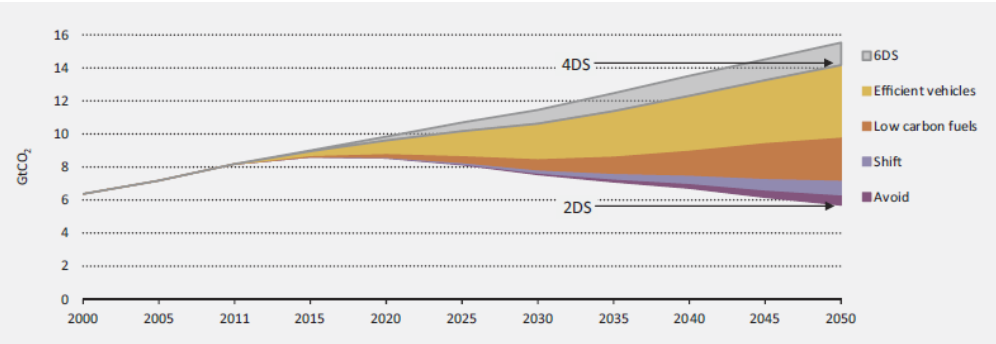

Figure 4 - WTW emissions reductions from transport in 4DS and 2DS

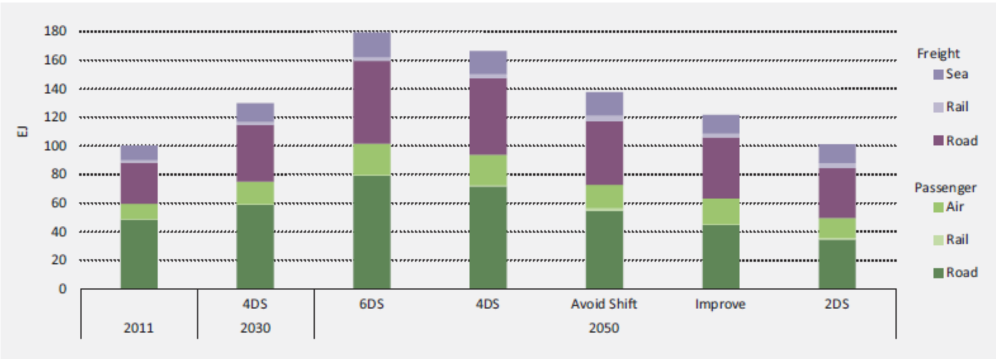

Figure 5 - Global energy consumption in transport by scenario

Dependency on oil in the transport sector is high due to: high energy density; easy handling and existing infrastructure; and cost competitiveness compared to alternatives. Gobally, in a business as usual scenario oil is expected to remain the dominant fuel in transport accounting for 85% of transport energy demand in 2040 (New Policies Scenario / 4DS), emphasising the need for additional action to reduce emissions in transport. Road transport would continue to account for around three quarters of transport oil demand. While aviation would be the fastest growing transport energy demand (expected to grow by 50% until 2050), road transport would still account for two thirds of transport oil demand growth. But in OECD countries transport oil demand would decrease in all sub-sectors except aviation. As freight transport demand is expected to grow faster than passenger transport demand, diesel would surpass

[10] IEA (2015), World Energy Outlook, International Energy Agency, Paris
[11] IEA (2015), Energy Technologies Perspectives, International Energy Agency, Paris

gasoline demand in the 2030s. But, such a scenario is not compatible with meeting future ambitions of mitigating climate change.

Alternative fuel penetration in energy scenarios is largely driven by the need to reduce GHG emissions, but other forces may be at play too. For example, more stringent sulphur, NOx and PM limits concerning waterborne transport, are likely to lead to a switch from residual fuel oil to middle distillates together with exhaust treatments and ultimately much cleaner fuels such as LNG. The deployment of alternative energy in transport is expected to grow, representing roughly half of energy demand in 2050 (in a 2DS scenario). Reliance on liquid fuels however persists, leading to a high demand for alternative liquid fuels as a result (around one quarter of transport energy demand).

The EU follows the general trends of OECD countries in the IEA scenarios[12], as illustrated by Figure 6. In a reference scenario transport energy demand stays roughly constant out to 2050 with gasoline demand decreasing substantially as a result of efficiency improvements and electrification of LDVs, diesel demand stays roughly constant with efficiency gains offset by increased freight travel demand, aviation demand increases gradually. Alternative fuels play a role similar in size to that projected by the IEA (in the New Policies / 4DS scenario) for OECD countries across different transport modes. More ambitious GHG emissions reduction targets require significant further improvements in reducing demand and in using alternative fuels, with alternative fuels contributing over half of transport energy demand in such scenario. However, it is not possible to expect that all sectors can equally benefit from biofuels due to restrictions in available biomass. A later section in this report provides a brief review of the potential for biofuels and other alternative renewable fuels.

---

[12] IEA Scenarios:

- The 2°C Scenario (2DS) is the main focus of *Energy Technology Perspectives*. The 2DS lays out an energy system deployment pathway and an emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C. The 2DS limits the total remaining cumulative energy-related CO_2 emissions between 2015 and 2100 to 1 000 GtCO2. The 2DS reduces CO_2 emissions (including emissions from fuel combustion and process and feedstock emissions in industry) by almost 60% by 2050 (compared with 2013), with carbon emissions being projected to decline after 2050 until carbon neutrality is reached.

- The 4°C Scenario (4DS) takes into account recent pledges by countries to limit emissions and improve energy efficiency, which help limit the long-term temperature increase to 4°C. In many respects the 4DS is already an ambitious scenario, requiring significant changes in policy and technologies. Moreover, capping the long-term temperature increase at 4°C requires significant additional cuts in emissions in the period after 2050.

- The 6°C Scenario (6DS – reference scenario) is largely an extension of current trends. Primary energy demand and CO_2 emissions would grow by about 60% from 2013 to 2050, with about 1 700 $GtCO_2$ of cumulative emissions. In the absence of efforts to stabilise the atmospheric concentration of GHGs, the average global temperature rise above pre-industrial levels is projected to reach almost 5.5°C in the long term and almost 4°C by the end of this century.

Available at: https://www.iea.org/publications/scenariosandprojections/

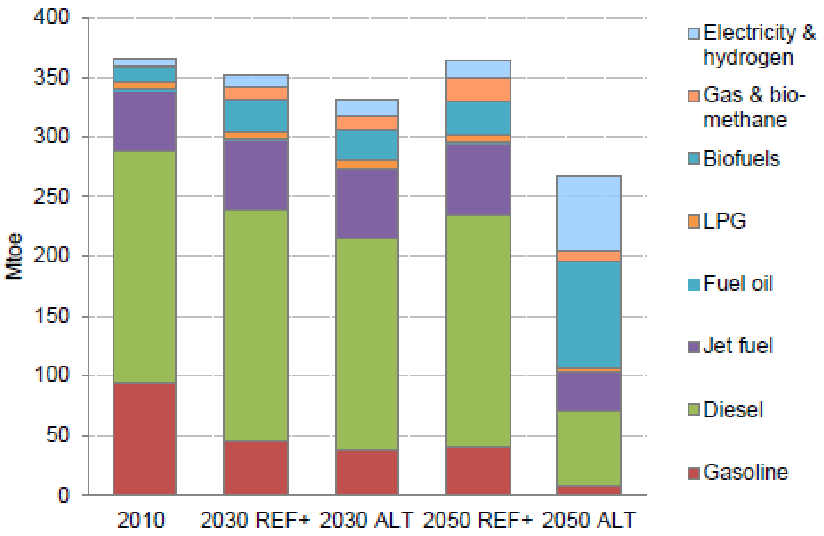

Figure 6 - Final energy use in land transport under current trends and adopted policies and under an alternative scenario achieving 60% GHG emissions reduction by 2050, EU28

These scenarios illustrate the importance of alternative fuels in achieving future decarbonisation scenarios. Given the likely continued demand for liquid and gaseous fuel in all transport modes in the long term (albeit to different extents), prioritising use in different modes over time could be based on the range of benefits that alternative fuels can bring to a particular mode. From a GHG perspective displacing petroleum based fuels in any sector is likely to bring similar benefits, so additional benefits in terms of air quality improvements, infrastructure costs, fungibility with current assets (drop-in fuels) and affordability become important distinguishing considerations. In terms of R&I an additional consideration in relation to prioritisation is to foster those areas of public and private sector R&I where the EU is most competitive and the potential impacts across different objectives are greatest. Also, consideration should be given to the potential export markets of innovative technologies in other regions of the world affected by pollution and decarbonisation.

1.4 GHG emissions savings from alternative fuels in the EU 28

According to the IEA's Energy Technologies Perspective the use of conventional fuels will need to rapidly decrease (as a result of efficiency gains and modal change) and the share of alternative fuels will need to rapidly increase in order to achieve a 2 degree scenario. In the absence of alternative fuels some transport modes (maritime and aviation) cannot decarbonise.

The 2 degrees scenario implies savings of roughly 800Mt CO_2 (Figure 8) compared to current emissions, of which the use of biofuels could contribute around 200Mt CO_2 by 2050 (Figure 9), provided that advanced biofuels production does not lead to increased emissions from direct or indirect land-use changes and average CO_2 emission savings over conventional fuels is 70%.Biofuels use would grow from a current value of roughly 615PJ (14.7 Mtoe, 3.2% of total energy use in transport) to about 3,150PJ (75.3 Mtoe, 24.4% of total energy use in transport).

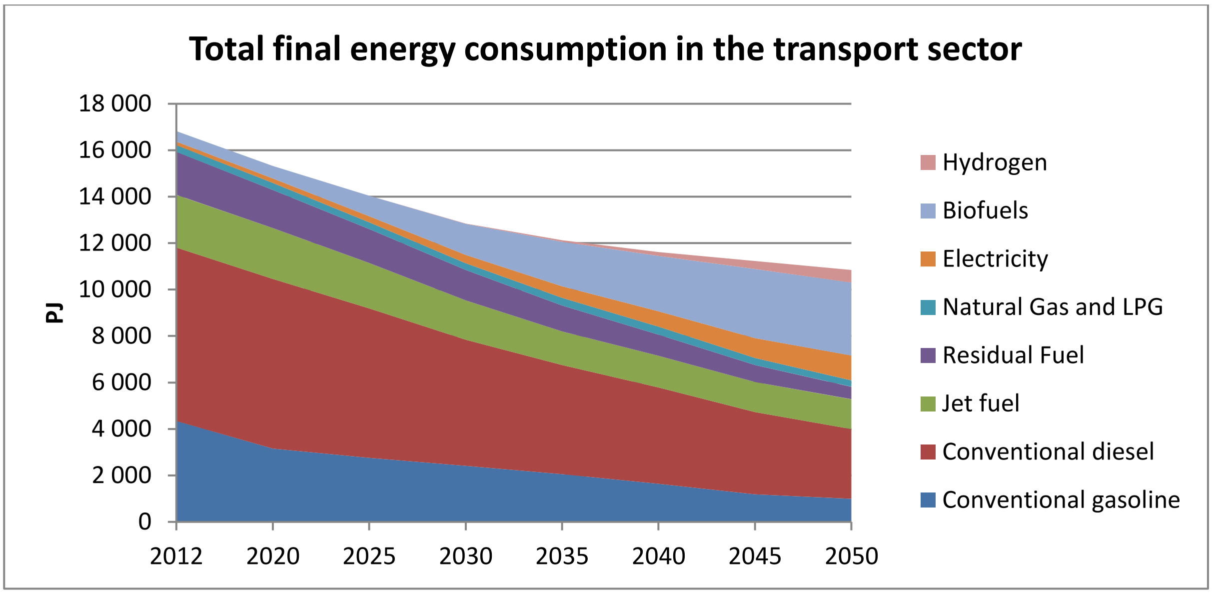

Figure 7 - Total energy consumption in the transport sector in the 2 degree scenario in EU28 (PJ) (Source: IEA ETP (2015))

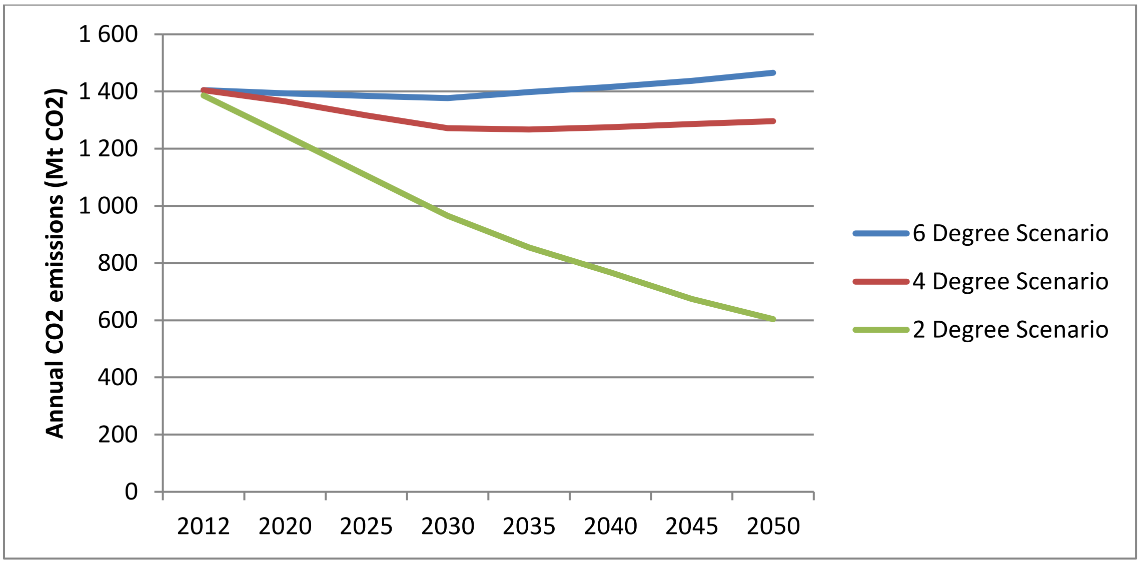

Figure 8 - Annual CO2 emissions from transport in different scenarios in EU28 (Source: IEA ETP (2015))

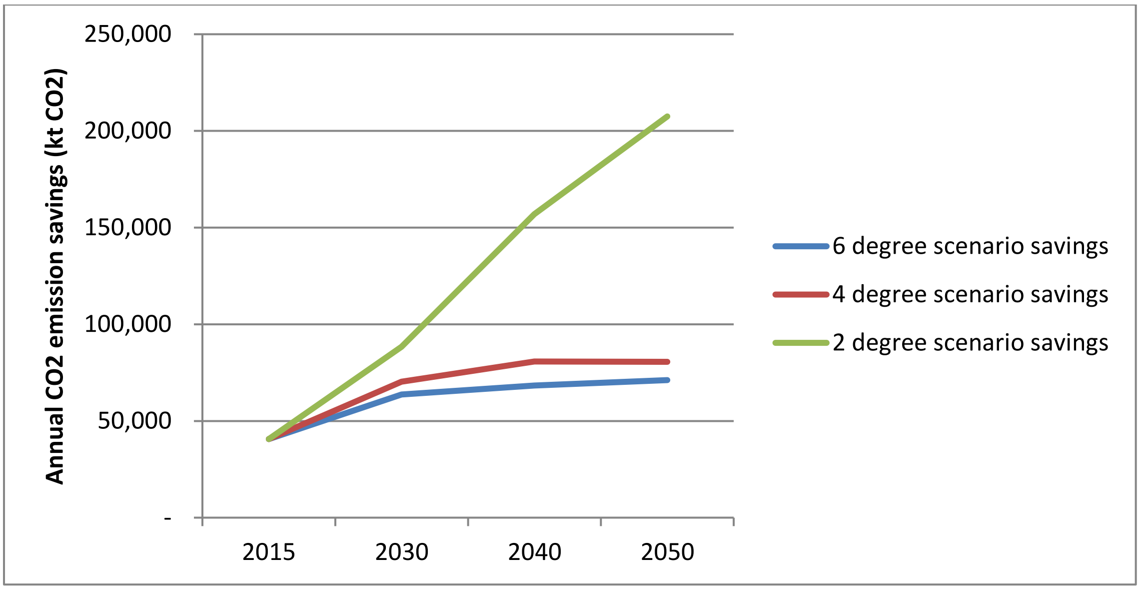

Figure 9 - Annual CO2 savings resulting from using biofuels instead of conventional fuels in EU28 (Source: IEA ETP (2015))

2 Objective, scope and approach of the STRIA on Alternative Fuels end-use

The aim of the STRIA on Alternative Fuels is to identify R&I priorities to improve, accelerate and maximise the impact of the use of alternative fuels in transport, focus public and private funding in this area, and contribute to alignment of the EU & MS research agendas.

It will take into consideration the future prospects for alternative fuels use in the context of other options and trends for meeting energy and environmental objectives in transport and the availability of alternative fuels. Specifically, it will consider the potential evolution of electromobility and its impact on other powertrain technologies and their fuels.

A technical glossary is provided in Appendix 7.2.

2.1 Scope

The STRIA on Alternative Fuels wishes to be comprehensive in its coverage of transport modes, possible alternative fuels and the powertrains they can be used in.

The alternative fuel categories considered for the different transport modes are provided in Table 2, bearing in mind that hydrogen and electricity are the subject of a separate STRIA on electromobility. The STRIA focuses on the engine technology therefore the fuel categorisation is based on chemical and physical properties of the fuels. The fuels considered could be of renewable of fossil origin, but while some alternative fuels of fossil origin could have benefits in relation to air quality and energy security, for example, compared to incumbent fossil fuels, achieving significant GHG emissions savings would rely on renewable alternatives.

Table 1 - Alternative fuel categories and transport modes considered by the STRIA

	Road		Rail	Waterborne	Aviation
Fuel categories	**LDV**	**HDV**			
Methane-based (liquid)	■	■	■	■	
Methane-based (gas)	■	■			
LPG, bioLPG	■	■			
Alcohols, ethers & esters	■	■	■	■	
Synthetic paraffinic fuels	■	■	■	■	■

Examples of fuels included in the different categories are provided in Table 2.

Table 2 – Fuel categories considered and examples considered by the STRIA

FUEL CATEGORIES	Examples
Methane-based fuels	CNG, LNG, bio-methane, E-gas
LPG (Propane- and Butane-based fuels)	LPG, BioLPG
Alcohols, Ethers & Esters	Ethanol, Butanol, Methanol, MTBE, ETBE, DME, BioDME, FAE
Synthetic paraffinic and aromatic fuel	GTL, HVO, BTL, SIP, ATJ, CH, SAK

The powertrain technologies considered in scope for the STRIA are provided in Table 3.

Table 3 – Powertrain technologies considered by the STRIA

TECHNOLOGY Powertrain category	Powertrain technology	Acronym	Specific examples
Spark Ignition	Spark Ignition / assisted combustion	SI	CAI
Spark Ignition	Spark Ignition - lean combustion	SI - lean	Both homogeneous lean and stratified lean
Compression Ignition	Compression Ignition	CI	HCCI, PPC (also includes PPCI, GCI, LTGC and other low temperature combustion systems that are not spark assisted
Compression Ignition	Compression Ignition - Dual Fuel	CI - DF	Such as NG dual fuel (including HPDI) or methanol dual fuel where the pilot fuel is a diesel type fuel for ignition purposes
Fuel cell	Fuel Cells other than hydrogen fuelled ones	FC	Direct Methanol Fuel Cell, LNG FC
Turbine	Turbine	Turbine	Turbofan aircraft engines

Table 4 below provides a definition of the transport modes considered.

Table 4 – Transport modes definition

TRANSPORT MODES	
Category	Definition
Light Duty Vehicles	Road vehicles <3.5T for people and goods transportation
Heavy Duty Vehicles	Road vehicles =>3.5T for people and goods transportation
Rail	Rail locomotives for people and goods transport[13]
Waterborne	From inland waterways to ocean going[14]
Aviation	Jet aviation[15]

2.2 Approach

The following approach was taken to identify the strategic research and innovation priorities in relation to alternative fuel use in different transport modes:

- Identify **options** for using alternative fuels (i.e. alternative fuel and powertrain combinations)
- Assess the **potential impact** of different uses of alternative fuels based on criteria that reflect policy objectives (**GHG savings (TTW via engine efficiency); air quality pollutants reduction; energy diversification; EU competitiveness**)
- Identify **challenges and opportunities** for improved or novel use of alternative fuels
- Identify **research needs** to accelerate development of alternative fuel use, with focus on high impact options (i.e. options that are likely to have greatest impact on across the criteria considered)
- Identify **requirements to address R&I needs**

In developing the STRIA, the following aspects need to be considered:

- Trade-offs between the different criteria of interest in relation to policy objectives
- Level of impact vs ease of implementation of alternative fuel options
- The timeframe over which the R&I can have an impact on the market

Extensive stakeholder consultation was conducted in preparing the STRIA on Alternative Fuels, through a survey, interviews and a stakeholder workshop held on 24 May 2016. The list of stakeholders consulted is provided in Annex 7.4.

3 State of the art on alternative fuel end-use

The following sections describe the status, trends and barriers of alternative fuels in transportation. Table 5 below shows current and future applicability of fuel and powertrain combinations to different transport modes, based on the following indicators:

- **Commercial in use**, meaning that the technology is mature and that it is currently sold into the market commercially

[13] Only non-electrified locomotives are considered here

[14] Smaller boats for recreational use are not considered here

[15] Only passenger and freight turbofan aircrafts are included. General aviation and particularly vehicles using AVGAS are not considered in this document due to their small size as energy consumers. Also, many are using standard automotive fuels and would therefore decarbonize in parallel to these.

- **Under development**, meaning that industry is actively developing products that are likely going to be launched into the market within 10 years
- **Research stage**, meaning fundamental research is undertaken, and products using this technology are not expected to be market ready within 10 years

Table 5 – Maturity of fuel and powertrain combinations

Fuel Type	Powertrain	LDV	HDV	Waterborne	Rail	Aviation
Methane based liquid & gas	**SI**	Commercial	Commercial			
	CI		Current dual fuel technology unable to meet Euro VI. New compliant technology under development & potentially available in 2017	Commercial as dual fuel and dedicated gas engine applications.	Under development	
	Turbine			Research stage		
LPG	**SI**	Commercial - retro-fit technology. CEN standard in place	Under development		Research stage	
Alcohols, ethers, esters	**SI**	Commercial - Ethanol and M&ETBE are widely blended into gasoline.	Under development	Under development		
	CI	Commercial - FAME widely adopted as blend with diesel.	Commercial - DME & ED95 in dedicated fleets. FAME widely adopted as blend with diesel	Commercial as dual fuel application with methanol.	FAME use under development . Other fuels at research stage	
	FC	Research stage	Research stage	Research stage	Research stage	
SPF	**SI**					

Fuel Type	Powertrain	LDV	HDV	Waterborne	Rail	Aviation
	CI	Commercial – HVO used in vehicles. Under development – FT-diesel properties being investigated	Commercial – HVO used in vehicles. Under development – FT-diesel properties being investigated			
	Turbine/ Turbofan		Research stage			Commercial – HEFA in use. Under development - various SPK fuels
Other	**SI**	Research stage- Gasoline / Naphtha				
	Composite piston-turbo cycle	Research stage				

3.1 Light Duty Vehicles

Light Duty Vehicle technology and the fuels it uses are driven by tail pipe emission limits as well as fleet average CO2 tail pipe targets. Both these emissions are currently measured across the New European Drive Cycle (NEDC), following a particular testing procedure to determine roadload and other factors. This testing procedure will be replaced in 2017 by the World Harmonised Test Procedure (WLTP) with a Real Driving Emissions (RDE) as an additional test procedure to ensure real world compliance within certain conformity factors for pollutant emissions. Fuel standards for gasoline and diesel are in place (EN228 and EN590 respectively). EN228 allows the blending of alcohols and ethers to set amounts, for example 10% of ethanol by volume. FAME (biodiesel) is allowed to be blended into fossil diesel up to 7% by volume (8% in France).

The fleet average CO2 targets are set at 95g/km for 2021 and could be reduced to between 68 & 78g/km by 2025[16]. So far these targets have driven large scale uptake of diesel especially for the larger and heavier vehicles that do significant mileage such as larger passenger vehicles and vans due to the higher efficiency of the diesel cycle. This and fuel taxation favouring diesel has created a diesel / gasoline ratio that is significantly biased towards diesel (2.6 in 2015) [1, 38]. As a consequence the EU is an importer of diesel and an exporter of gasoline, potentially making the displacement of diesel by alternative fuels more attractive for refiners and in balance of payments terms. In the medium term it is expected that the CO2 targets will drive a wide-scale uptake of new engine and vehicle technology in

[16] http://www.europarl.europa.eu/sides/getDoc.do?type=REPORT&mode=XML&reference=A7-2013-151&language=EN

the LDV sector including increased levels of electrification and hydrogen. These energy vectors are the subject of the STRIA on electromobility, however electrification through hybridisation will have an impact on engine size and consequently on the type of engine and its fuel compatibility. A systems approach is required for the development of such powertrains. Increased electric propulsion power does mean that engines can be further optimised to operate more efficiently and more cleanly within a smaller speed / load operating window as well as have lower transient requirements.

EU emission standards apply to all motor vehicles and limits the permissible tailpipe emissions of CO, HC, NOx, PM and PN. Current Euro6 standards came into force in 2013. Very effective aftertreatment devices such as the Three Way Catalysts (TWC) for most gasoline vehicles and oxidation catalysts combined with a Lean NOx Trap (LNT) and / or Selective Catalytic Reduction (SCR) as well as a Diesel Particulate Filter (DPF) for diesel vehicles are available and in operation today. These systems, especially the diesel aftertreatment systems, can be costly, which could become another driver to push the development of alternatively fuelled powertrains. For example fuels without carbon to carbon bonds inherently demonstrate very low levels of particulates, which would allow the engine to be optimised for lower GHG and NOx emissions leading to lower aftertreatment system costs, which in turn would offset possible engine adaptation costs for alternative fuels. The introduction of limits beyond EURO 6c or a tightening of the RDE conformity factors (not currently foreseen) would require additional aftertreatment control systems making gasoline and diesel engine technology more expensive to produce and potentially more expensive to operate.

On the fuel side, the Renewable Energy Directive (RED), with a renewable energy in transport target of 10% by energy by 2020, has been the main driver for the growth in alternative renewable fuels in road transport.

CEN standards exist for Gasoline (EN228), Diesel (EN590), LPG (EN589), paraffinic fuels (EN15940), B10 (EN14214), and are under development for natural gas and E85. Gasoline and diesel are widely available throughout the EU. Various MSs have a separate pump for E10. Sweden has a significant E85 forecourt infrastructure. LPG is relatively widely available throughout the EU. A relatively dense natural gas (CNG) infrastructure exists in MSs, such as Austria, Belgium, Bulgaria, Czech Republic, Germany, Italy, the Netherlands, Sweden and Switzerland ,other MSs such as the UK and Ireland have hardly any CNG filling stations[17]. The LNG infrastructure is developing partly through the LNG Blue corridor projects, but is far from dense enough. While private infrastructure is already sufficient for many applications, public infrastructure for electric vehicles is expanding rapidly, but is not dense enough in some areas to provide an integrated network, in particular as far as fast charging is concerned. Fragmentation of the connectors and of the payment methods further contributes to this lack of coherency in the eyes of the end user. Hydrogen infrastructure is developing especially in Germany, the UK and Scandinavia, but still in its infancy. The latter two will be covered in STRIA on Electromobility.

Research and innovation needs for the LDV sector, including a timeline, are captured by Ertrac [7] in the figure below and are broadly aligned with the findings in this report. Current research activities focus strongly on pollutant emissions reduction to meet upcoming Real Driving Emissions as well as improving vehicle efficiency to meet fleet tailpipe CO2 targets. Beyond this most research focuses on new high efficiency, low polluting combustions systems that work well in combination with increased levels of vehicle electrification. These include Homogeneous Charge Compression Ignition (HCCI), Cold Air Intake

[17] http://www.cngprices.com/station_map.php

(CAI), Partially Premixed Combustion (PPC), Low Temperature Combustion (LTC) and others, but essentially they share the aim of efficient combustion at lower temperatures to reduce engine out NOx emissions and are therefore captured in this report under the broad category of Low Temperature Combustion (LTC) systems. Developing a suitable novel combustion system taking into account the potential of alternative fuels should be a priority.

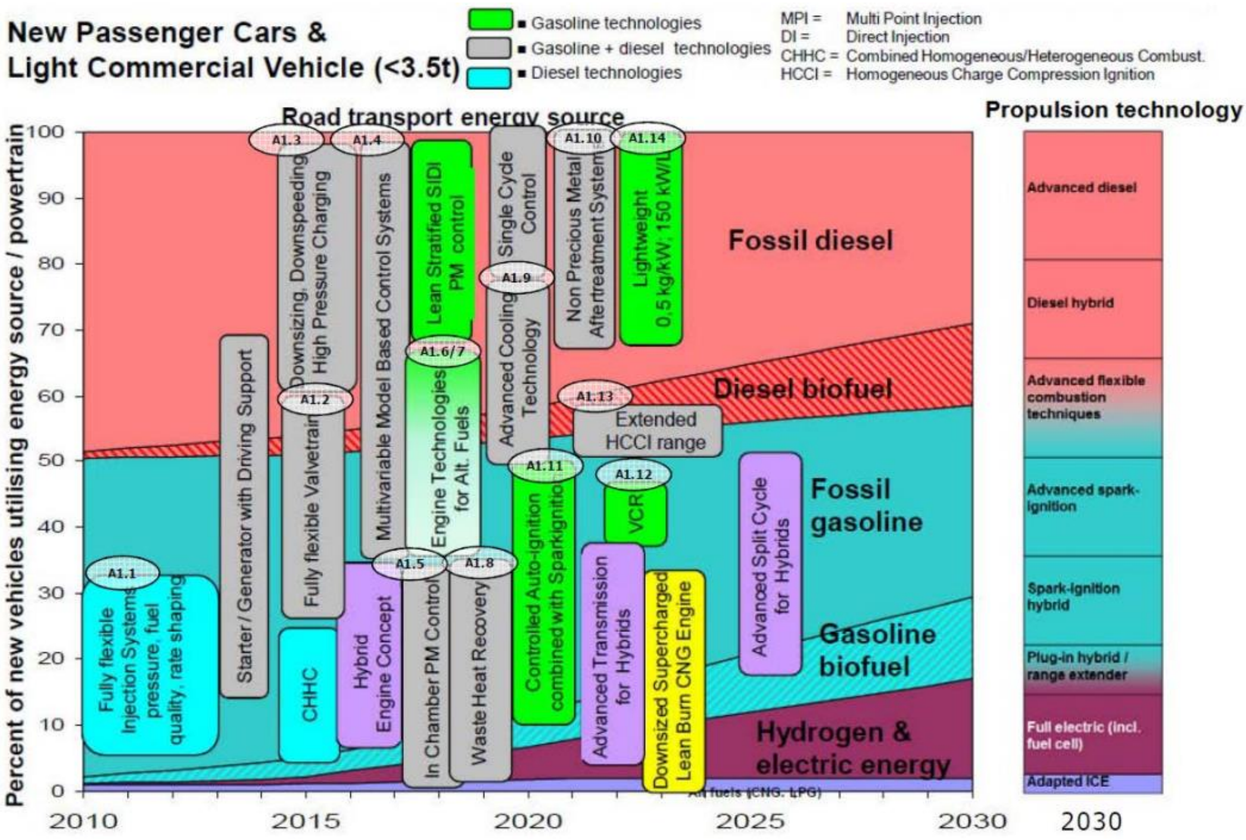

Figure 10 - Research and innovation needs for the LDV sector. Source: Energy Carriers for Powertrains Ertrac [7]

Table 6 provides a summary on the state of the art of alternative fuel use in LDVs.

Table 6 – State of the art on alternative fuel use in LDVs

LDV

	Natural Gas / Bio-methane / E-gas	Alcohols, ethers & esters	Synthetic paraffinic fuel (FT, HVO, GTL)	Liquid petroleum gas and bioLPG
How much is used and why?	There is renewed interest in natural gas for transportation recently. For the LDV sector this is partly driven by the lower carbon content of the fuel per unit of energy resulting in lower tailpipe CO2 emissions helping OEMs to meet the 95gCO2/km target. Improving air quality is also an important driver. For HDVs lower noise levels may also be a consideration. Lower fuel cost as a result of lower fuel duty per unit of energy compared to gasoline and diesel has helped the uptake of this technology.	The use of ethanol and FAME has steadily been increasing to satisfy RED requirements	Not used Europe-wide on a large scale yet. HVO used in large quantities in Finland.	LPG consumption in LDVs is driven by lower fuel costs comparing to Diesel.
How is it used?	Natural gas (including dual-fuel), bio-methane E-gas use in light duty vehicles is typically in adapted spark ignition engines. The gas is combusted homogeneously and a Three Way Catalyst (TWC) is used to meet tail pipe emissions legislation. The gas is commonly stored in a 200bar on-board pressure tank. Vehicles with these engines and fuel tanks are widely commercially available in Europe directly from the manufacturer. The technology can also be retrospectively added to the vehicle.	Ethanol is the most widely used alcohol blended into gasoline up to 10% (v/v) [4]. Small amounts of methanol and higher alcohols are also allowed to be blended into gasoline within EN228 limits. E85 is used in FFVs in certain areas within the EU (such as Sweden, France and Germany). MTBE & ETBE are commonly used ethers blended into gasoline. FAME is currently blended into diesel up to around 7% (v/v) within EN590 limits. Higher blend ratios or pure FAME is used in dedicated fleets. EN228 and EN590 fuels do not require vehicle modifications. Fuels outside the specifications need relatively minor well understood changes in order to operate	Synthetic (drop-in) fuels can in principle be used as substitutes (in any blend ratio) for diesel, gasoline and jet fuel.	LPG is typically used in Spark Ignition engines through relatively simple modification of the original vehicle. LPG is stored as a liquid under approx. 5bar pressure, gasified in the vehicle and injected in the ports or manifold. This technology is widely commercially available and widely used across the EU. LPG as a motor fuel is covered by the EN589 standard.

Trends	CEN/TC 408 standard for natural gas and biomethane for use in transport and CEN/TC 326 standard for natural gas vehicles - fuelling and operation are being developed and will help increase the uptake of gas and promotion of the CNG infrastructure development, as the existence of standards helps various parties across the supply chain. Depending on the variation in gas specification allowed in the standard, engine efficiency improvements are to be expected due to the high octane of methane gas which is strongly synergetic with downsizing. It was reported in [2] that the share of natural gas/ biomethane mixtures is expected to increase to 8.3 – 12.5 Mtoe by 2020 (5% market share in the transport sector) and 20.8 – 25Mtoe by 2030 (10% market share). It is thought that this is due to a combination of consumers willing to buy a CNG vehicle due to the lower operating costs and OEMs willing to produce due to the lower CO2 emissions.	E10 and B7 limits constrain uptake. Sustainability concerns over use of raw vegetable oils for FAME will constrain supply. ILUC Directive cap of 7% by energy contribution from food-crop based biofuels may constrain growth [3, 39].	The technology is at an early commercial stage. Production capacity is already at 5.7 million tonnes GTL per year and close to 3 million tonnes HVO per year [4]. However, this production mainly takes place outside Europe.	LPG is widely established and has slowly been growing.

Vehicle challenges & opportunities	CNG is a suitable option for LDVs. The additional cost of especially the tank can be offset with the lower fuel cost (due to the lower fuel duty). Engine efficiency improvements due to high octane of methane gas, synergetic with downsizing.Significant variation in the make-up of grid natural gas makes engine optimisation a challenge. Standardisation of the fuel quality for CNG and bio-methane under CEN/TC 408 would help with engine optimisation and use in gasoline and diesel engines, and isis expected to be voted upon in early 2017The previous publication of EN 16726 Gas infrastructure - Quality of natural gas - Group H provided an initial step in gas standardisation .	New engine & vehicle technology is required to accommodate higher levels of alcohols and ethers in SI engines. These changes are well understood, mature and relatively cost effective. The higher octane of alcohols and ethers are synergetic with downsizing and should lead to increased thermal efficiency for optimised engines, which might partially compensate the lower energy content. Higher FAME blends are possible, but require engine and fuelling system changes and would most likely require aftertreatment considerations. Higher ethanol content would require some infrastructure change.	No real challenges for adoption of these fuels in transport as they are direct replacements up to any level of the incumbent fuels.	There are no technical barriers for further increasing use of LPG in LDVs. Engine efficiency improvements are possible due to the high octane of LPG, assuming the standardised composition, which is strongly synergetic with downsizing. Direct injection of liquid LPG could allow for further downsizing, potentially enhancing the thermal efficiency of the engine further.
Other technical and infrastructural barriers	Lack of forecourt infrastructure in certain MSs remains the main barrier to uptake of CNG. Currently MSs such as Austria, Belgium, Bulgaria, Czech Republic, Germany, Italy, the Netherlands, Sweden and Switzerland have well developed CNG infrastructure. Methane slip throughout the WTT pathway presents a challenge, which needs to be further analysed and mitigated with new technologies. Transportation competes with power generation and heating for sustainable gas. The overall availability of sustainable gas and the exact nature of the regulatory framework will likely determine the attractiveness of wide scale uptake of sustainable gas in transportation.	Within EN228 there is significant room to blend biofuels (mixtures of alcohols and ethers) and therefore replace more gasoline in the LDV sector. Alcohols in particular could however also be used as diesel replacement (such as ED95, see HDV sections), which in the longer term might be more desirable if the gasoline / diesel ratio in the EU becomes even more unbalanced. The FAME content in diesel can in principle be increased with adapted vehicle and engine technology and used in LDV, HDV and other diesel consuming machinery	Challenges are mainly around the production process scale and cost effectiveness. This depends largely on production volumes and prices relative to the alternative.	LPG forecourt infrastructure is established, but could be enhanced to stimulate more LPG vehicles. It is possible to use LPG as a dual fuel or blended with DME in CI engines potentially in LDV and HDVs

3.2 Heavy Duty Vehicles

Heavy duty road vehicles (trucks and buses) are predominantly powered by diesel engines currently. This is a consequence of the superior fuel efficiency and low end torque compared to SI engines resulting in better operating characteristics.

Diesel engines naturally suffer from high engine-out emissions, particularly NOx and Particulate Matter, which so far have been very successfully countered by increasingly sophisticated, costly, bulky aftertreatment systems. Cost effective alternative fuels that have cleaner combustion characteristics could therefore play a significant role in powering the HDVs of the future. Currently the focus seems to be mainly on LNG, but many other options could contribute. These could include DME, ethanol or methanol with an ignition improver, HVO or some of the other synthetic paraffinik kerosenes (SPKs), while increased levels of FAME with improved aftertreatment systems could also play a role, even though some of these alternatives entail modifications in the engines and infrastructure and might therefore not be optimal from an overall system standpoint.

Current research activities in the HDV sector focus strongly on improving fuel consumption for lower cost of operation of the complete vehicle. For the powertrain this focuses on reducing waste energy as well as high efficiency, low polluting combustions systems. These combustion systems are available in various formats and have a large number of names (HCCI, CAI, PPC, LTC and others), but essentially share the aim of efficient combustion at lower temperatures to reduce engine out NOx emissions and are therefore captured here in Low Temperature Combustion systems (LTC). Research into a number of different alternative fuels is ongoing (including DME, ED95, NG) and for OEMs the focus is strongly focused on developing cost-effective system solutions integrating varying levels of electrification with combustion engines depending on typical duty cycles the product will experience. This is also shown in figure 9 where “hybridisation” and “transient electric research” go hand in hand with engine “right sizing” and “high efficiency research narrow operation”. Research is also taking place on the electrification of roads[18].

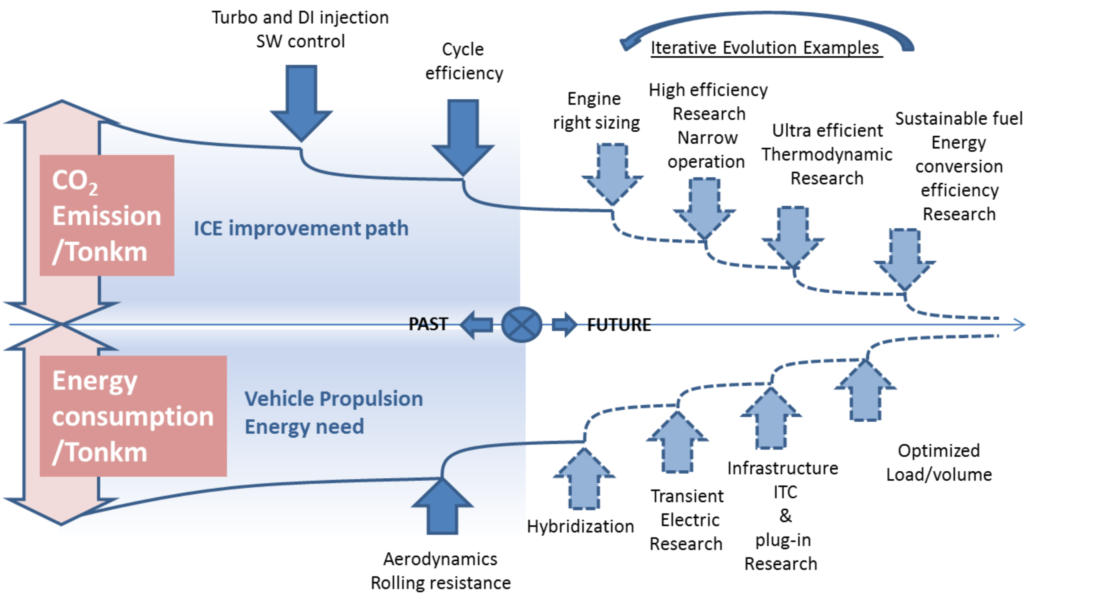

Figure 11 - Schematic ICE HD research needs in relation to HD vehicle energy consumption [7]

[18] https://www.scania.com/group/en/first-electric-road-nearly-ready-for-operation/

Table 7 provides a summary on the state of the art of alternative fuel use in HDVs.

Table 7 – State of the art on alternative fuel use in HDVs

HDVs

	Natural Gas / Bio-methane / E-gas	Alcohols, ethers & esters	Synthetic paraffinic fuel (FT, HVO)	Liquid petroleum gas and bioLPG
How much is used and why?	There is renewed interest in natural gas for heavy duty transportation recently. For the HDV sector this is largely driven by the much lower fuel duty per unit of energy compared to diesel and the Euro VI emissions requirements. The increase in re-fuelling stations availability has helped the uptake of this technology.	The use of FAME has steadily been increasing to satisfy RED requirements	Not used in Europe on a large scale yet, except HVO in some countries like Finland.	Negligible use in HDVs

HDVs

	Natural Gas / Bio-methane / E-gas	Alcohols, ethers & esters	Synthetic paraffinic fuel (FT, HVO)	Liquid petroleum gas and bioLPG
How is it used?	Natural gas and bio-methane use in heavy duty vehicles is currently mainly in spark ignition (SI) engines. These engines typically have a lower efficiency than incumbent diesel engines, while compliance with Euro VI standard is simpler as it only needs a Three Way Catalyst. Natural gas is also used in dual fuel CI engines, but these do not currently meet the EURO VI methane emission limits. A second generation of dual fuel engines utilising High Pressure Direct Injection is being developed by a number of OEMs targeting EURO VI compliance while retaining diesel like efficiencies The gas is either stored in 200bar on-board pressure tanks (CNG) or in cryogenic liquid form (LNG). LNG has a higher energy density than CNG and is therefore used for long distance haulage. The technology is commercially available in Europe. The technology can also be retrospectively added to the vehicle.	Biodiesel and particularly FAME are extensively used in HDVs through blending (up to 7% by volume) with diesel. Higher blend levels up to B100 are used in dedicated fleets. The use of alcohols with an ignition improver is commercially available from Scania. Volvo has developed DME engines which can be commercialised once the fuel becomes available. The uptake of alcohol and DME engines is currently very limited.	Synthetic fuels can be used as substitutes (in most blend ratio) for diesel, gasoline and jet fuel assuming the finished fuels meet the appropriate standards.	The use in HDVs is currently insignificant, but could possibly be interesting for dual fuel applications.

HDVs

	Natural Gas / Bio-methane / E-gas	Alcohols, ethers & esters	Synthetic paraffinic fuel (FT, HVO)	Liquid petroleum gas and bioLPG
Trends	CEN/TC 408 standard for natural gas and biomethane for use in transport and CEN/TC 326 standard for natural gas vehicles - fuelling and operation are being developed and will help increase the uptake of gas and promoting of the LNG infrastructure development. Various projects (such as the LNG blue corridor and GasOn) are currently running in Europe to increase the infrastructure and technology availability. Increasing engine efficiency while maintaining practical engine characteristics and low emissions are the key focus. These include SI lean combustion, HCCI and PPCI and use of heat recuperation to benefit of the higher temperature of SI exhausts. Much research also takes place in further optimising dual fuel engine and aftertreatment technologies. It was reported in [2] that the share of natural gas/biomethane mixtures is expected to increase to 8.3 – 12.5 Mtoe by 2020 (5% market share in the transport sector) and 20.8 – 25Mtoe by 2030 (10% market share).	DME and ED95 applications have been developed by Volvo and Scania respectively and are commercially available. So far the uptake has been limited to mainly buses in Sweden due to infrastructure requirements. VTT is currently researching methanol with an ignition improver (MD95). Some higher biodiesel applications exist also in the field in dedicated fleets.	The technology is at an early commercial stage. Production capacity is already at 5.7 million tonnes GTL per year and close to 3 million tonnes HVO per year. However, this production mainly takes place outside Europe.	LPG is predominantly thought of as a fuel for spark ignition engines. A High Pressure Direct Injection dual fuel system has apparently been developed for application in HDVs (workshop discussion)

HDVs

	Natural Gas / Bio-methane / E-gas	Alcohols, ethers & esters	Synthetic paraffinic fuel (FT, HVO)	Liquid petroleum gas and bioLPG
Vehicle challenges & opportunities	LNG is a suitable option for long haul HDVs, where CNG is better suited to shorter distance HDVs and LDVs. Natural gas is also used in dual fuel CI engines, but these do not meet the EU VI methane emission limits. A second generation of dual fuel engines utilising High Pressure Direct Injection is being developed by a number of OEMs targeting EURO VI compliance while retaining diesel like efficiencies. The additional cost of especially the LNG tank can be offset with the lower fuel cost (due to the lower fuel duty). Standardisation of the fuel and increasing the forecourt infrastructure are key enablers to increase uptake. Methane slip from the whole fuel chain is a significant concern and is being addressed with research and technology improvements. Reducing methane emissions from on-board fuel storage and evaporation require further investigation	Higher FAME (TAME) blends have been demonstrated to be possible, but require engine and fuelling system changes and would most likely require aftertreatment considerations. The wider uptake of alcohol based fuels either with a premixed ignition improver, as a dual fuel application or in an optimised SI engine could be of interest. While ED95 technology is mature and a reference fuel standard exists, the other technology would need some further development and the fuels standardising. DME technology is available and relatively mature. ASTM and ISO standards exist which could be translated into a CEN standard.	No real challenges for adoption of these fuels in transport exist as they are direct replacements of the incumbent fuels. Challenges are mainly around the production process scale and cost effectiveness	SI engine efficiency improvements are possible due to the high octane of LPG, assuming the standardised composition, which is strongly synergetic with downsizing. Direct injection of liquid LPG could allow for further downsizing, potentially enhancing the thermal efficiency of the engine further. Dual fuel could also unlock further efficiency improvements, but would require significant aftertreatment equipment to meet Euro VI

HDVs

	Natural Gas / Bio-methane / E-gas	Alcohols, ethers & esters	Synthetic paraffinic fuel (FT, HVO)	Liquid petroleum gas and bioLPG
Other technical and infrastructural barriers	Lack of infrastructure remains the main barrier to EU wide take up of LNG. CNG was covered in the LDV section. Currently only certain MSs such as Spain, the UK and the Netherlands have developed LNG infrastructure. The LNG blue corridor project is aiming to add a significant number in strategic location to develop a practical network across Europe. Methane slip throughout the WTW pathway and variation in the make-up of grid natural gas present further challenges. Transportation competes with power generation and heating for (sustainable) gas. The overall availability of sustainable gas and the exact nature of the regulatory framework will likely determine the attractiveness of wide scale uptake of (sustainable) gas in transportation.	Within EN228 there is significant room to increase ethers. Alcohols in particular could be used as diesel replacement which in the longer term might have more impact. The FAME content in diesel can in principle be increased with adapted vehicle and engine technology and used in LDV, HDV and other diesel consuming machinery. There is currently no DME infrastructure.	This depends largely on production volumes and prices relative to the alternatives	There are no real technical barriers for further increasing LPG in HDVs. The infrastructure would need to be adapted / upgraded for HDVs however

3.3 Rail

The railway network in the EU in 2010 was 212,800 km with 112,000 km of electrified rail lines [9]. All member states rail strategies favour further electrification, but there are routes where electrification is not economically viable. On these routes locomotives fuelled with alternative fuels can play a role.

In 2010 GHG emissions from the railways sector were 7.4 MtCO2eq, excluding emissions from electricity consumption, representing 0.6% of transport share (UIC/IEA 2014). Rail engines are classed and regulated as Non Road Mobile Machinery (NRMM). This is currently at stage IV with stage V emission regulation under consideration and can be found in the 2004/26/EC directive [11, 23]. In the 2010 "Rail Sector Strategy 2030 and beyond" [24], the European rail sector set a vision to reduce specific energy consumption by 50% by 2050. Also, by 2030, the European railway sector has targeted to reduce total emissions of NOx and PM10 by 40% and aims at zero emission by 2050. Developing flexible engine systems able of maximum fuel conversion efficiency, and integrating emissions reduction technologies and hybrid propulsion systems will contribute to achieve these targets [24] in areas where electrification is not an option.

To meet increasingly ambitious emissions reductions and efficiency gains, rail transport is considering the use of alternative fuels such as liquefied natural gas (LNG), liquid biofuels, synthetic fuels and hydrogen, and also looking at improvements in energy efficiency and weight reductions. Biodiesel (FAME) could also be an alternative fuel [9, 10]. However, existing diesel traction engines running with blends in excess of B30 can lead to increased fuel consumption and decreased power, and higher maintenance costs. The use of liquefied natural gas (LNG) is also beginning to gain interest as an alternative rail propulsion system [25, 26]. Considering the chemical composition, LNG and biomethane (LBG) offer reductions of pollutant particulate matter emissions and tailpipe GHG emissions. The WTW GHG emissions of LNG depend largely on the levels of methane slip and source of the gas. However, this technology is considered for new locomotive development rather than for retrofitting of existing ones, due to the extra-space needed for LNG tanks. Hybrid diesel-electric locomotives that capture braking energy and store it in batteries can offer significantly reduced energy consumption and lower emissions. If the technology develops sufficiently to be cost-effective, larger scale energy storage on electric trains could provide them the ability to run on non-electrified routes [12]. Another technology considered by the rail industry in the drive towards zero emissions is fuel cells.

Table 8 provides a summary on the state of the art of alternative fuel use in rail transport.

Table 8 – State of the art on alternative fuel use in rail

RAILWAY

	Biodiesel	LNG / Liquid biomethane / Egas
How much is used and why?	No use reported in Europe. B20 (ASTM D7467) was tested in 2010/2011 in the US	Diesel prices in Europe remain considerably higher than NG on an energy-equivalent basis [26]. LNG is used in pilot demonstrator in Spain, with claims that NOx, CO and PM are reduced by 70%, and GHG by 20-30%. Russian Railways have tested gas-reciprocating traction technology in 2015, while in 2013 trials began of the world's first LNG-powered locomotive (TEM19).
How is it used?	AMTRAK (USA) and BNSF Railway (USA) used B20 for one-year tests	TEM19 with gas reciprocating engine has modular design and is equipped with multifunctional microprocessor control and monitoring system. LNG is stored in a removable cryogenic tank.
Trends	A number of European rail operators have carried out trials on rail vehicle and engines (e.g. French SNCF, German DB, Czech CD, Hungarian MAV).	Trials have also taken place other countries e.g. Canada, and small scale liquefaction technology, such as GE's MicroLNG, could allow to liquefy natural gas at any point along a gas distribution network. Lower running costs associated with LNG are appealing
Vehicle challenges & opportunities	Challenges include: Lower energy content Poor low temperature starting / operation Poor oxidation stability and water absorption characteristics Opportunities include: Higher cetane number and flash point as well as improved lubricity Biodegradable and low toxicity (these are similar for all vehicles and depend on the blend ratio)	Technology not available for retrofitting the existing locomotives. Modular design significantly simplifies locomotive maintenance and repairs. It takes less time to warm up the engine in the cold weather/regions.
Other technical and infrastructural barriers	Incompatibility with certain elastomers and natural rubbers. More rapid lubricating oil degradation. Degradation during long-term storage.	Switching from diesel fuel to LNG would require a new delivery infrastructure for locomotive fuel

3.4 Waterborne transport

Waterborne transport from recreational craft to large ocean-going cargo ships is driven primarily by diesel engines (around 99 %). Approximately 77% of waterborne fuel consumption is low-quality,

low-price residual fuel referred to as heavy fuel oil (HFO), which tends to be high in sulphur (2.7%) [13]. The Waterborne transport sector has internationally recognised standards that define the characteristics of fuel oils and what they can contain so that they will be suitable for use on-board ships, ISO 8217:2012 being the most widely used standard. The next edition is expected in 2016 which could include biodiesel blends as a new series of distillate waterborne fuel grades [20].

Alternative fuels are considered in waterborne applications due to emission legislation. These include SOx regulations for operating in the Sulphur Emissions Control Areas[19] (SECA) and force ship operators to either install expensive exhaust after treatment equipment or switch to low-sulphur fuels. Directive 2012/33/EU sets limits at 1.5% sulphur in waterborne fuel oil for all ships in the North Sea and the Baltic Sea; 1.5% sulphur in fuel for all passenger ships in the other EU seas, and 0.1% sulphur fuel at berth in ports. European inland navigation is classed and regulated as Non Road Mobile Machinery (NRMM). This is currently at stage IV with stage V emission regulation under consideration and can be found in the 2004/26/EC directive [11, 23].

Outside of European waters, Canada and the US coastline have the first introduced emission control zone for SOx, NOx and PPM's in 2016. NOx is regulated by the MARPOL NOx standards for all ships built since 2000 [21, 30].

In 2010 GHG emissions from the total European navigation sector were 171.4 MtCO2eq (19.3 MtCO2eq from inland navigation and 152.1 MtCO2eq from maritime transport) excluding international bunkers (international traffic departing from the EU), representing 14.1% of transport emissions [21]. By 2050, the target for maritime transport is to reduce GHG emission by 40% compared to 2005 [22]. But, the current trend points to an increase in future shipping GHG emissions as a result of projected growth in global trade. Significant measure in relation to energy efficiency and fuel substitution are required [27].

Alternative low(er) carbon fuels such as biofuels, methanol and methane based gases (CNG, LNG) can help satisfy the above requirements by substituting the fossil fuels currently in use. But, where dedicated engines are used fuels will need to be available in sufficient quantities worldwide or regionally for bunkering. Currently, the focus is mainly on LNG, but methanol is also receiving significant interest, with Stena Line deciding to retrofit one of its vessels to use methanol [9, 16, 29, 30]. The Alternative Fuel Infrastructure directive (Directive 2014/94/EU) requires national action plans for LNG bunkering facilities.

Current research activities in waterborne transport are concentrated on combustion systems to reduce emissions and fuel consumption. This includes research on dual-fuel engines and advanced fuel injection systems to reduce emissions while maintaining or improving energy efficiency. Partially pre-mixed (and other forms of low temperature) combustion systems combined with exhaust gas re-circulation and waste heat recovery are also topics of research for the same reasons. Methane leakage throughout the fuel supply and storage chain could (partly) offset GHG emissions and requires further research.

Table 9 provides a summary on the state of the art of alternative fuel use in waterborne transport.

---

[19] MARPOL annex VI. Established SECA in Baltic, North Sea and English Channel where a phased reduction of SOx emissions was initiated. The allowable amount of fuel sulphur was reduced to from 1.5% to 1.0% in July 2010 and is to be further lowered to 0.1% in January 2015.

Table 9 – State of the art on alternative fuel use in waterborne transport

Water-borne	LNG / Liquid biomethane / E-gas, CNG	Alcohols & esters	Synthetic paraffinic fuel (FT, HVO)
How much is used and why?	Depending on the combustion and after treatment technology used, LNG can lead to significant emissions reductions. Reductions of 85–90% for NOx, near 100% for SOx and PM and 15-20% for GHG emissions were reported [14]. Methane slip (the release of unburnt methane) is a challenge but technologies are available to overcome some of this. The first LNG-fuelled ferry based on DNV GL standards was launched in 2000 [17]. In EU 50 LNG-fuelled ships (excluding LNG carriers) are in operation – thereof 44 operate in Norway and 2 in other MSs. In addition, 45 LNG-fuelled ships are on order [19]. In 2016, very large cruise ships are on order with LNG dual fuel capability. CNG has a lower power density but is easier to handle and is feasible for recreational and inland craft.	Interest in methanol as ship fuel is growing in response to the need to reduce SOx emissions. In 2015 STENA Line launched the first methanol powered ferry [9, 29]. The NOx emissions from methanol are 45 % of those of conventional fuels and SOx emissions are 8 % of those of conventional fuels (per unit energy). Further reductions are possible with aftertreatment Ethanol is blended with gasoline in small boat engines [9]. Butanol has similar energy density and octane number as gasoline, which allows higher blends without affecting the energetic performances. Biodiesel blend (B20) was tested with good results in US.	Not yet used in European waterborne transport [30].

Water-borne	LNG / Liquid biomethane / E-gas, CNG	Alcohols & esters	Synthetic paraffinic fuel (FT, HVO)
How is it used?	LNG as a shipping fuel is a proven and available solution, with gas engines covering a broad range of power outputs. LNG is burned either in stoichiometric or lean burn SI engines, in dual fuel direct injection (diesel cycle) engines. In the future, LNG maybe used in high temperature fuel cells to achieve greater engine efficiencies.	Methanol can be used in waterborne transport for inland as well as for short-sea shipping, where it is currently being tested. Methanol is combusted according to the diesel process, using a small amount of pilot fuel (MGO or HFO) for ignition. In July 2013 DNV released rules for using low flashpoint liquid (LFL) fuels, such as methanol. Biobutanol (iB16) fuel blend was tested in US in standard Waterborne engines with no alterations to the engine or fuel system. Biodiesel can be used in blends (up to 20 %) with Waterborne diesel oil or Waterborne gas oil without affecting engine performance. The new standard is expected in 2016.	
Trends	For maritime transport, the implementation of Directive 2012/33/EU of 21 November 2012 as regards the sulphur content of Waterborne fuels is expected to be a driver for the promotion of LNG for ships [2]. 80 LNG-powered ships are under construction, with planned deliveries by 2018 (DNV GL, 2015) Market studies predict that the LNG demand for Waterborne sector will reach 5.2 Mtoe in 2020 and 8-12 Mtoe in 2030 [15]. The alternative fuels infrastructure directive[20]requires national plans to foresee the deployment of LNG fuel infrastructure in ports.	The environmental assessment of methanol produced from biomass has the potential to reduce life-cycle emissions by over 80% for GHG, SOx, NOx and PM, which is similar to LBG [40]. There are already demands on methanol as alternative fuel. Methanex has ordered 4 tanker ships on methanol. Waterfront Shipping has commissioned 7 new chemical tankers with dual fuel methanol engines to be delivered in 2016 [29] The technology for biobutanol is not yet mature but US DoE anticipates the potential availability at industrial level.	The Dutch Energy Vision estimates penetration for GTL as a fuel in the inland shipping sector to 11% by 2030 and 19% by 2050, and in recreational vessels to 19% in 2030 and 31% in 2050 [2].

[20] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0094

Water-borne	LNG / Liquid biomethane / E-gas, CNG	Alcohols & esters	Synthetic paraffinic fuel (FT, HVO)
Vehicle challenges & opportunities	LNG propulsion technology is ready for application and has successfully been deployed on inland vessels since 2011 [2]. Further research and demonstration need to address above all methane slip due to its climate effect. Standardisation of the filling station for waterborne transport LNG and greater bunkering capacity would allow further development of new LNG-fuelled ships and also support increased deployment via the retrofitting of ships to LNG [18] and promotes gas (LNG & L-CNG) delivery in regions where gas is currently unavailable. LNG offers significant environmental benefits in particular when it is blended with liquid bio-methane [20]. Maximising storage efficiency and minimising boil off is a challenge. In comparison to road, marine combustion engines are already highly efficient. Potentially greater efficiencies maybe achievable through electric propulsion and high temperature LNG fuel cells.	For using biodiesel in existing ships, the fuel system may have to be modified with biodiesel-compatible components. Biodiesel, especially in higher concentration, can dissolve certain non-metallic materials (seals, rubber, hoses, gaskets) and can interact with certain metallic materials (i.e. copper and brass). For new ships and engines this is much less of a concern [30]. Methanol has a heating value close to LNG (LNG with 20.3 MJ/litre and methanol has 19.8), which entails a similar performance [2]. Also, it has a relatively low flashpoint, is toxic (skin contact, inhaled or ingested) and its vapour is denser than air. As a result, changing fuels poses new challenges to operators in terms of handling and safety. The conversion of an existing engine to burn methanol would bear less costs than an LNG retrofit work [2, 29].	

Water-borne	LNG / Liquid biomethane / E-gas, CNG	Alcohols & esters	Synthetic paraffinic fuel (FT, HVO)
Other technical and infrastructural barriers	LNG demands more space for fuel tanks, leading to a decrease in payload capacity [17]. Relatively high capital cost for the system installation [17]. The current low NG price compared to the conventional oil fuel is a main economic driver for this new application. However, the current lack of LNG bunkering infrastructure presents an uncertain picture for the LNG fuel price. This leads to uncertainty for ship operators on whether they could benefit from the offset between fuel cost savings and large capital investments. There is a limited refuelling infrastructure and an unharmonised regulatory approach for standardisation in MSs, which will be handled by the new standardisation foreseen by CEN/TC 326 standard for natural gas vehicles - fuelling and operation [15]. Due to the lower energy density on the intercontinental Europe Asia Route, fuelling within the Middle East may be required. The availability of adequately trained port, fuelling and crew in the safe use of LNG must be ensured. Safety of LNG during fuelling and collision must be ensured.	The new mandatory notation LFL FUELLED covers aspects such as materials, arrangement, fire safety, electrical systems, control and monitoring, machinery components and some ship segment specific considerations. The availability of adequately trained port, fuelling and crew in the safe use of methanol must be ensured.	

3.5 Aviation

Efforts made through technological progress and operational improvements have improved significantly the energy efficiency of air transportation. However, even with the most radical technological progresses, the efficiency gains will not offset the expected traffic growth nor to allow to achieve the challenging commitments for decarbonisation made by the aviation industry by 2020 and 2050 [31]. Synthetic fuels (drop in fuels) produced from renewable sources are expected to play a key role to cover this gap by 2050 [31].

Commercial aviation commonly uses Jet-A1 (also known as kerosene). Due to the high cost of aircrafts and the long fleet replacement time, and also to limit infrastructure changes, the aviation sector is likely to rely on liquid fuels similar to kerosene to 2050 and possibly beyond, and is currently looking to drop-in sustainable fuels to the conventional, crude based, jet fuel i.e. fuels that when blended allow existing jet fuel specifications to be met. The composition of these new fuels is currently mostly paraffinic, being known as Synthetic Paraffinic Kerosene (SPK) or iso-paraffins. There are 5 major fuel routes approved for its use in civil aviation: FT-SPK, HEFA-SPK, HFS-SIP, FT-SPKA/A and ATJ-SPK. There are other seven routes currently under approval process, plus other 15 waiting to enter the process [32]. Sustainability of those pathways depends upon the feedstock and way of production. Feedstocks considered by the aviation industry[21] are waste oils like used cooking oil (UCO), residual animal/vegetable oils from industries, vegetable oils like camelina oil , tobacco, jatropha, sugars from sugarcane, lignocellulosic material, lignin residues, municipal solid wastes (MSW) or algae. Wastes and residues that don't require land to be produced usually have less sustainability concerns. Drop-in fuels could also be produced from electric power (power-to-liquid (PTL) or sunlight (STL)).

The alternative fuels mentioned are used blended with conventional Jet-A1 according to the limits established by the standard ASTM 7566. Once blended, the fuel is considered as Jet-A1 (ASTM 1655 or DEFSTAN 91-91) and can be used in all civil infrastructures and aircraft that use jet fuel, which is a key advantage to avoid duplication of infrastructures or operations [33]. The blend is needed because the synthetic hydrocarbons fuels do not contain some hydrocarbons naturally present in fossil fuels such as aromatics, or other elements such as Sulphur, that are known to play a relevant role for the performance of the aircrafts fuel systems. Overall, these properties make the sustainable fuels cleaner at combustion (clearly for PMs and potentially NOx) and with higher energy content (per weight unit) that translates to some limited energy efficiency gains (due to the reduced weight to be transported and a slightly more efficient combustion). However, the role of those compounds and their interaction with other parameters in the jet fuel are not fully understood, and knowledge is based on experience with fossil fuel rather than with these new synthetic alternatives. This means that understanding the optimal properties and limits of blends requires further work.

Most production and use of alternative fuels in commercial aviation has been for demonstration and/or R&I purposes. Recently, the R&I profile of the use has changed with the blended use of HEFA-SPK at Oslo airport [34] and the start of continuous production of HEFA-SPK by Altair in Los Angeles (CA) for use by United Airlines [35]. The incentive programs available in the USA and in particular in

[21] The feedstocks types cannot be considered sustainable per se. Sustainability should be demonstrated along the production chain. Those mentioned above have been used in aviation because in particular production chains they have been found as sustainable according to internationally recognized standards like RSB (www.rsb.org) or ISCC (www.iscc-system.org) and the Directive 2009/28/EC.

California for advanced biofuels are enabling Altair production and are also driving the building of another facility for FT-SPK based on municipal solid wastes [32]. At European level, the only incentive for airlines using biojet fuel is the EU ETS for intra-European flights but it is negligible compared with the price gap. However, at global level, there is a commitment for development and implementation a global carbon market mechanism (GMBM) from 2020 that could be an incentive for the use of sustainable, low carbon fuels but that, with the current layouts, would be also unlikely covering the price gap for biojet.

The available production capacity of alternative fuels for aviation and its use is still limited globally, and is growing faster in USA than in Europe. This is due mainly to the lack of market due to the high costs of the technology and insufficient policy incentives e.g. compared to road transport. This is very much related to the difference between aspirational and mandatory targets. Also, the limited development of sustainable feedstock supply chains is a constraining factor.

Recent developments in technology are leading to better affordability and higher availability, as well as higher GHG emissions reductions. But, due to the investment and time needed for the approval of new technologies for use in aviation, time to market of these new technologies could be significant without external support. For example, the approval of the latest technology from alcohols (Alcohol-to-Jet - ATJ) has taken more than 5 years to be approved with costs in the range of several million euros [22].

Table 10 provides a summary on the state of the art of alternative fuel use in aviation.

[22] ASTM Task Force item in ASTM D02-J6 was initiated by Gevo® in June 2010, final approval obtained in April 2016. Extensive fuel property and engine/aircraft testing is required for the process, making it costly. At the end, the time for completing the process is uncertain for the fuel producer, as the total costs, due to that more/less fuel and tests would be needed depending on the findings. It is expected from ASTM to optimize the process to reduce the hurdle, but there are still limitations regarding the number of testing facilities available as there are many (around 20) pathways looking for the approval and more could join.

Table 10 – State of the art on alternative fuel use in aviation

Jet Engines	SPK (FT, HEFA, FT/A)	SIP	ATJ	HEFA+	LNG
How much is used and why?	Not used in Europe on a large scale, there is a growing interest about develop this fuels as they are considered large contributors for decarbonisation of air transport in the short and medium term [31]. More than 1600 commercial flights have been done using sustainable fuel blends from 20-50% [36]. Use at airport as non-segregated fuel has started in January 2016 in Oslo [34] increasing the number of flights, but the volumes needed to keep continuous supply are a challenge. There is no continuous production of drop-in fuels for aviation in Europe. Use outside Europe, mostly in USA, has been promoted by military contracts and now starting from private companies.	Used at Lab'line demonstration project and some Airbus delivery flights, but not used on a continuous basis.	Recently approved, no use reported in Europe.	HEFA+ refers to an upgrading from the conventional green diesel (HVO) to the aviation quality standards (cold temperature properties, density…). Not yet approved for commercial aviation, but testing is ongoing.	Not used.
How is it used?	Synthetic paraffinic kerosene, once it has been blended, can be used as drop-in jet fuel. Maximum blend ratios accepted for commercial aviation are: FT-SPK (50%), HEFA-SPK (50%) and FT-SPK/A (50%) [33]. Once the fuel has been blended and approved according the ASTM D7566 standard, it can be used in all civil aircrafts and infrastructures using conventional jet fuel without any segregation.	It can be used blended with fossil jet fuel up to 10% v/v [33].	Can be used blended with fossil jet fuel up to 30% v/v [33].	HEFA is approved up to 50%. HEFA + could be probably used blended with fossil jet fuel up to 10% v/v [33].	It is not drop-in, requires radical change of airframe and combination with electricity still not in the market.

Jet Engines	SPK (FT, HEFA, FT/A)	SIP	ATJ	HEFA+	LNG
Trends	The technology is at an early commercial stage and the production capacity is still limited, which is mainly due to economic reasons. However, HEFA is an industrially mature technology. Recently a production facility in Los Angeles (CA, USA) has started continuous production of HEFA, able to produce about 30,000 t of HEFA-SPK per year [35]. Besides, outside Europe, there are several offtake agreements from airlines or governments, but considering facilities still not running. In Europe, potential production capacity according to the EU Flightpath and the latest updates could reach 15,000 t of sustainable fuel (FT-SPK) per year in France from 2018 [37].	The technology is at an early commercial stage with low availability.	The technology is at an early commercial stage with low availability.	The technology is a commercial stage with high availability. It could be easily adopted with some ‘minor’ adaptations. HEFA (Green Diesel) is well developed for ground transport fuels but the extension of HEFA+ is still to be approved.	Possibilities of using LNG as jet fuel are being explored
Challenges & opportunities	There are almost no challenges due to their drop-in characteristics at the defined blend ratios, but to reach pure use is still not possible (but could potentially be). Minimum content in aromatics related to fuel system seals is one of the limitations to unblended use while it has been identified that there the nvPM emissions lower when aromatics are also lower. Different aerosols, nvPM and shoot combustion profiles from SPK suggest different nonCO2 effects at high altitude that would need better understood to know the real decarbonisation potential. Use of low blend ratios of green diesel (as HEFA+ for aviation) SPK could suddenly increase the production capacity and would increase the uptake but there is still some fuel system testing required.	This is a unique molecule vs the incumbent what is more complex. It has reported that the 10% blend ratio could be difficult to be higher.	Same as SPK, but blend ratio unlikely to be enlarged.	Use of low blend ratios of green diesel (as HEFA+ for aviation) SPK if approved could suddenly increase the production capacity and increase the uptake in the short term, but there is still some fuel system testing required to know the limits. It wouldn’t be a long term solution due to the low blend ratios.	Non drop-in is not feasible in the time frame for a real implementation but it could be a solution for the future.

Jet Engines	SPK (FT, HEFA, FT/A)	SIP	ATJ	HEFA+	LNG
Other technical and infrastructural barriers	Challenges are mainly around the production process scale and cost effectiveness. This depends largely on production volumes and prices relative to the alternative. For new fuels and modification of current blending limits, costly ASTM processes are a barrier. A better understanding of fuel composition limits (fit for purpose) could help to reduce the barrier significantly. There is no other alternative for aviation for decarbonisation or/and fuel independence in the short/medium term. There are some technical constraints for the use of shared civil-military infrastructures as NATO pipelines that need to be tackled to increase the use. The global character of aviation is a challenge regarding competitiveness. As opportunity, developing the compatibility standards of new technologies, the economic constraint could be overcome.				Long time to market, infrastructure

3.6 Summary of trends in alternative fuel R&I

Underlying themes of vehicle powertrain research are increased efficiency and lowering of noxious emissions. Alternative fuels could help with these aims, but the extent depends on their characteristics and levels at which biofuels are blended. As a result engine improvement efforts tailored to alternative fuels will depend on the levels of gains that could be achieved and how biofuels will be used. A brief overview of the main R&I activities is provided below by fuel type.

3.6.1 Methane-based fuels

Significant efforts are currently underway to develop High Pressure Direct Injection equipment, which is effectively an improved dual-fuel injection system, and optimised dedicated gas combustion systems. Lean operating dedicated gas engines are being developed for waterborne applications. There is also evidence that dual fuel technology is being developed further to increase diesel substitution rates and minimise methane slip for heavy duty road and waterborne transport. The focus on light duty vehicles is on further downsizing by making use of the high octane of these fuels. On-board storage of especially LNG also attracts significant R&D attention across the transport modes in order to make it cheaper, easier to install and lower leakage. Biomethane and power-to-gas technologies could enable a transition to lower carbon content fuels.

A significant number of projects have been conducted focussed on CNG and LNG for both heavy and light duty road transportation. Figure 12 gives an overview EU funded activities and their focus.

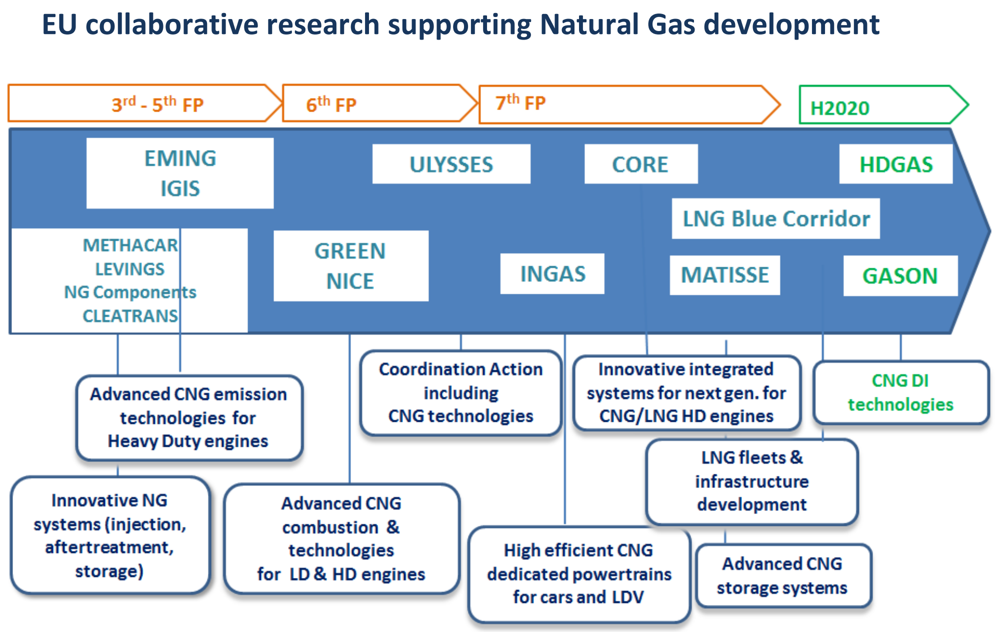

Figure 12 - EU funding actions and industrial outcomes on Natural Gas technologies for road transport (source: Ertrac Future light and heavy duty ICE powertrain Technologies) [7]

There is also significant activity within industry at the moment which is not covered in the above figure, including EURO VI compliant dual fuel combustion systems for HDVs, including methane slip. Methane slip remains an issue throughout the fuel supply chain to the engine, while aftertreatment systems can reduce tailpipe emission to very low levels. R&I efforts are required to reduce the WTT methane emissions, and possibly evaporative emission from on-board fuelling systems.

LNG use in shipping is growing using largely based on dual fuel engines that allow operation on both fuel oil and natural gas.

3.6.2 LPG

Some of the activities discussed in the methane-based fuel section also apply to LPG, specifically around HPDI. For LPG this currently appears to mainly involve the LDV sector even though the technology is equally applicable to HDV and some waterborne applications.

3.6.3 Alcohols, esters and ethers

There is a significant amount of work looking at taking advantage of the higher octane of alcohols and ethers in Spark Ignition engines. The same applies to higher ester blends in diesel for use in Compression ignition engines for the Light Duty and Heavy duty transport modes. A number of academic institutions are researching high efficiency dedicated alcohol engines. DME and ED95 are commercially available products awaiting the roll out of infrastructure. Further work in this area concentrates on improved efficiency, reduced noxious emissions and lowering cost. Work is also underway to research methanol with an ignition improver (MD95), and there is a significant level of activity on dual fuel systems using methanol in the waterborne sector in order to improve efficiency and lower noxious emissions. The rail sector could benefit from the efforts led by other sectors. A number of companies and institutions are developing methanol and ethanol fuelled fuel cell technology for mainly LDVs, HDVs and waterborne applications either as main propulsion or auxiliary power supply. The focus of this research is around cold start operation, high efficiency, reliability and cost.

An example of EU funded projects for land transport is the BEAUTY project which focussed on ethanol as a diesel substitute mainly for LDVs but failed to achieve significant improvements even when optimising the engines for the fuel's characteristics. For waterborne application methanol as a dual fuel application has been widely research in a number of projects as shown in Figure 13. In addition, the HERCULES-2 project is focussed on increased fuel flexibility of waterborne applications.

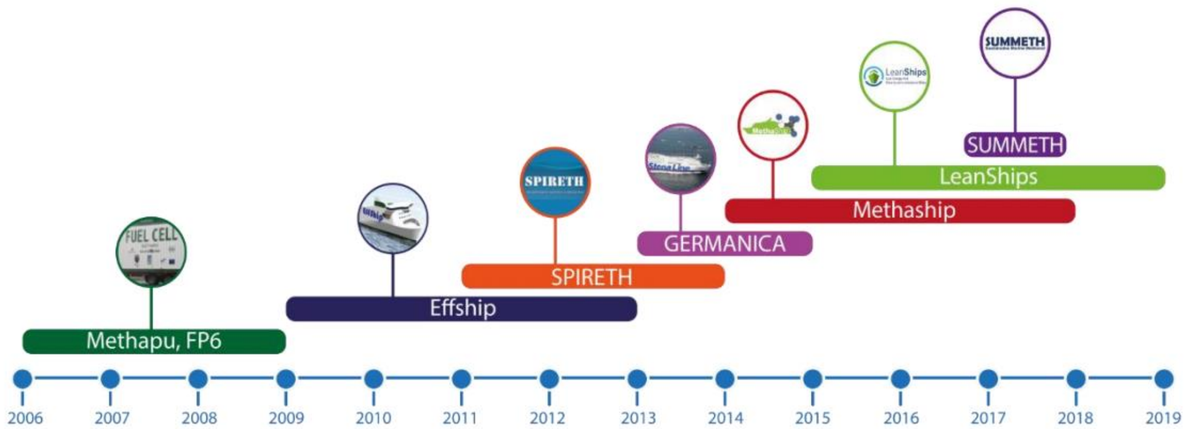

Figure 13 - Timeline showing some of the main projects investigating the use of methanol as a marine fuel [8]

3.6.4 Synthetic Paraffinic Fuels

SPKs are largely drop-in and would therefore require less engine development. Significant efforts are taking place in using HVO blended with diesel in mainly LDV and HDV applications. During the

stakeholder engagement workshop the consensus was that not enough is known about the exact properties of more novel SPK fuels and that therefore further research is required to investigate how powertrain technology could be further optimised.

4 Potential benefits of alternative fuel use in different transport modes and engines

Table 5 shows the multitude of options that are in use and being considered for different transport modes. From a technical point of view, there are two key distinguishing factors that are relevant to policy objectives: Well-to-Wheel GHG emissions and Tank-to-Wheel noxious emissions.

For the WTW GHG emissions it is important to understand that the majority of the benefit is likely to come from utilising renewable (low carbon) alternative fuels (WTT). A smaller but not insignificant contribution can be made by increased vehicle and therefore powertrain efficiency (TTW), which is the focus of this report. TTW noxious (pollutant emissions) contribute to the urban air quality issues experienced in cities across the world. It is however worthwhile noting that correctly regulated and implemented aftertreatment control systems such as found on EURO VI trucks, can address this issue. Certain alternative fuels and combustion systems have inherently lower engine-out emissions that might enable cost-effective aftertreatment systems for potential future pollution limits. This is discussed in more detail in section 4.1.

There are then two other factors that are potentially important in prioritising different options: EU competitive position and energy diversification.

EU competitive position relates to the extent that any fuel and technology option could provide a competitive advantage to the EU industry. Energy diversification relates to the potential of the option to contribute to the diversification of energy supply to different modes.

4.1 Alternative fuels effect on GHG and noxious emissions

Alternative fuels can have a positive impact on both TTW GHG and pollutant emissions due to their chemical composition and properties.

There are two main mechanism by which the fuel can reduce tailpipe GHG emissions. Firstly, fuels with a higher H/C ratio per unit of energy will automatically have lower exhaust CO2 emissions. Secondly, increasing the engine efficiency through utilising specific properties of the alternative fuel can bring about further CO2 reductions. Engines are typically developed with a particular fuel in mind. The narrower the specification of the fuel the more engine hardware and software can be optimised with respect to engine efficiency (GHG emissions) and pollutant emissions. For road vehicles this effect has been demonstrated over the years with gasoline and especially diesel, however in contrast , increased fuel processing to obtain a narrow fuel specification can in itself be more costly and GHG intensive. A balance between a narrow specification fuel with a fully optimised engine and a wider specification fuel with a less optimised engine would need to be found.

The improvement potential of TTW GHG emissions is important but relatively small (<10%) compared to the WTT improvements that switching to a low carbon, renewable fuel would have (>60%).

For pollutant emissions it is important to understand the difference between engine out and tailpipe emissions. Engine out emissions are not only a function of fuel, but also of the combustion process and combustion system design. Exhaust gas aftertreatment systems are widely used (and can be

very effective as demonstrated by heavy duty EURO VI compliant vehicles) to control tailpipe emissions to “within” the required limits set for the application. Lowering engine-out emissions will therefore not automatically result in lower tailpipe emissions, unless these are likely to be lower than any legal limits aimed at by aftertreatment systems. Lower engine-out emissions could however enable OEMs to meet lower emissions limits at a lower cost. Specifically, fuels without carbon to carbon bonds inherently demonstrate very low levels of particulates. This effect could be utilised to reach a better compromise between NOx and CO2 emissions in compression ignition engines. Within the marine sector where currently little or no aftertreament is used, switching from residual fuel oils to alternative fuels such as LNG or methanol offers the possibility of significant reductions in SOx (>90%), particulates and NOx emissions (>80%).

Table 11 below summarises promising fuel and powertrain technology combinations with regard to TTW GHG emissions and TTW noxious emissions, with a focus on alternative fuel induced technology improvements in different transport modes. The options below are derived from a literature review and consultation with stakeholders resulting in an assessment of fuel and powertrain technology combinations as captured in Appendix 7.3.

Table 11 - Summary table of most promising fuel and technology propulsion options by transport mode

	TTW GHG emissions	*TTW noxious emissions*	*Significant market deployment expected by**
LDV	**Alcohols and ethers in SI engine:** Use of alternative fuels with higher RON, such as alcohols, ethers and methane, could increase SI engine efficiency by up to 5%. This could allow further downsizing / downspeeding. Enleanment either stratified or homogeneous has the potential to significantly increase the engines thermal efficiency and hence lower CO2 emissions.	**Alcohols and ethers in SI engine:** Replacing gasoline and diesel with shorter HC chains potentially reduces engine out PM and NOx which could enable better engine optimisation. Aldehyde emissions would need to be monitored	**2030**
	Alternative fuels in Fuel Cells: Enabling FC introduction based on fuels such as alcohols could lead to GHG savings of 10-20% compared to spark ignition engines, depending on operating regime.	**Alternative fuels in Fuel Cells:** Enabling FC introduction based on fuels such as alcohols could lead to significant pollutant emissions reductions of nearly 100% in all emissions compared to SI engines. Aldehydes might be an issue	**2050**
	Gaseous (methane & LPG) fuels in SI engines: High Pressure Direct Injection systems are under development by e.g. Westport / Prins that aim to reduce CO2 by 10% relative to the current gas SI systems. OEMs are engaged in Low Pressure Direct Injection development, as well as other activities (e.g. GasOn project), with the aim to reduce CO2 by 20% relative to the current best in class SI CNG vehicles.	**Gaseous (methane & LPG) fuels in SI engines**: Replacing gasoline and diesel with shorter HC chains potentially reduces engine out PM and NOx which could enable better engine optimisation	**2030**
	SPFs: SPFs from a range of sources, including Power to Liquid (PTL), are considered potentially promising, but currently the impact of their specific properties on engine efficiency are not well researched.	**SPFs:** SPFs from a range of sources, including Power to Liquid (PTL), are potentially promising, but currently the impact of their specific properties on noxious emissions are not well researched.	

HDV	**Alcohols and ethers in CI engine:** DME & ED95 engines are commercially available and meet Euro VI. Engine efficiency is similar to diesel currently with further scope for improvement. High Pressure Direct Injection (HPDI) dual fuel systems currently being developed would also be suitable for alcohols & ethers. These engines have negligible engine-out PM emissions. **Gaseous (methane & LPG) fuels in CI engines**: HPDI systems are under development at e.g. Westport as a dual fuel application aiming at >90% diesel substitution (by energy) and meeting current diesel engine characteristics incl. efficiency. Technology developers also claim such engines would minimise methane leakage. **SPFs:** SPFs from a range of sources, including Power to Liquid (PTL), are considered potentially promising, but currently their level of sustainability, cost and impact of its specific properties on engine efficiency are not well researched.	**Alcohols and ethers in CI engine:** DME & ED95 engines are commercially available and meet Euro VI. No c-c bonds mean that engine-out particulate matter is significantly reduced allowing further improvement in NOx. Aldehyde emissions are understood to be minimal. **Gaseous (methane & LPG) fuels in CI engines**: It is anticipated that these systems will meet EURO VI limits. **SPFs:** SPFs from a range of sources, including Power to Liquid (PTL), are potentially promising, but the impact of their specific properties on noxious emissions are not well researched.	**2030** **2030** **2030**
Rail	**Alcohols and ethers in CI engine:** DME & ED95 engines are commercially available and meet Euro VI. Engine efficiency is similar to diesel currently with further scope for improvement. High Pressure Direct Injection (HPDI) dual fuel systems currently being developed would also be suitable for alcohols & ethers. **Gaseous (methane & LPG) fuels in CI engines**: HPDI systems are under development at e.g. Westport as a dual fuel application aiming at >90% diesel substitution (by energy) and meeting current diesel engine characteristics incl. efficiency. Technology developers also claim such engines would minimise methane leakage. **SPFs:** SPFs from a range of sources, including Power to Liquid (PTL), are being considered, but currently the impacts of their specific properties on engine efficiency are not well researched.	**Alcohols and ethers in CI engine:** DME & ED95 engines are commercially available and meet Euro VI. No c-c bonds mean that engine-out particulate matter is significantly reduced allowing further improvement in NOx. Aldehyde emissions are understood to be minimal. **Gaseous (methane & LPG) fuels in CI engines**: It is anticipated that these systems will meet EURO VI limits. **SPFs:** SPFs from a range of sources, including Power to Liquid (PTL), are potentially very promising, but the impact of their specific properties on noxious emissions are not well researched.	**2030** **2030**

Waterborne	**Alcohols and gaseous fuels in (dual fuel) CI engine:** Methanol and natural gas are currently used in dual fuel engines. Engine efficiency is similar than when operated on fuel oil with further scope for improvement of up to 5%. Engine operating fully on gas or methanol are currently under development promising further improvements in efficiency of aroud to 5% under certain conditions **SPFs:** SPFs from a range of sources, including Power to Liquid (PTL), are being considered, but currently the impacts of their specific properties on engine efficiency are not well researched.	**Alcohols and gaseous fuels in (dual fuel) CI engine:** Methanol and natural gas dual fuel engines have significantly lower NOx, SOx and particulate matter emissions. Engine operating fully on gas or methanol are currently under development promising further reductions in pollutant emissions **SPFs:** SPFs from a range of sources, including Power to Liquid (PTL), are potentially promising, but the impact of its specific properties on noxious emissions are not well researched.	**2030**
Aviation	**Synthetic hydrocarbon fuels as SPK, SIP or ATJ** Current synthetic jet blended fuels are promising fuels that would allow very small efficiency improvements of around 2% were mentioned by experts during the workshops.	**Synthetic hydrocarbon fuels as SPK, SIP or ATJ** Synthetic sustainable jet fuel are promising fuels that would allow NOx, SOx and nvPM improvements, especially linked with the aromatic compounds and sulphur content.	**2030**

** please note: Time of implementation is sometimes governed by infrastructure availability*

4.2 EU competitive position

Europe's competitive position relative to the rest of the world is in this context defined as the technology leadership of its industry. For alternative fuels this could either mean specific technology required to produce, refine and handle the fuels, or technology that focuses on on-board storage, handling, combustion, aftertreatment and control of these fuels.

Fuel production and infrastructure:

Europe has a strong position in the development of LNG refuelling infrastructure for fleets (HDVs, rail and maritime) with several large companies developing and building new infrastructure e.g. the LNG Blue Corridor project. It also has a strong position in biomethane production technologies via biological and thermochemical routes. There is also significant research and industrial activity for the production of alcohols and SPFs from biomass. There are several demonstration and early commercial projects for the production of ethanol and butanol from lignocellulosic biomass, methanol from glycerine and from synthesis of H2 and CO2, and SPFs. These activities complement the strengths in the traditional refining sector.

On-board technology:

Alternative fuels can present significant challenges for vehicle manufacturers. Overcoming these challenges through technological advances would generate new IP which would in turn strengthen Europe's leading position.

Specifically these would include:

- On-board CNG/LNG storage and handling for LDVs, HDVs, waterborne inland and marine transport and rail
- Gas or alcohol combustion, fuel handling and injection systems for LDVs, HDVs and waterborne transport
- Novel and advanced aftertreatment systems taking into consideration alternative fuel use and the disposal of the resulting residual wastes

Alternative fuels could also bring about opportunities especially for fuels with much tighter fuel specifications than gasoline, diesel, marine oil and jet fuel. Making full use of these properties by increasing engine efficiencies while reducing noxious emissions and reducing cost could potentially present a significant number of technological advances that Europe's industry is well placed to capitalise upon.

Maintaining the traditionally strong position the Europe has in transport related manufacturing needs to be maintained, as emphasised by the recent EC Communication on "A European Strategy for Low-Emission Mobility". Research and innovation in engine technologies compatible with alternative fuels could be an important element in maintaining this competitiveness.

Figure xx illustrates the importance of the the European automotive industry globally and in terms of employment, trade balance, innovation spending and tax income in Europe.

Key figures

EMPLOYMENT		
Manufacture of motor vehicles (EU28)	2.3 million people = 7.6% of EU employment in manufacturing	2012
Total (EU28 manufacturing, services and construction)	12.1 million people = 5.6% of total EU employment	2012
PRODUCTION		
Motor vehicles (world)	90.6 million units	2014
Motor vehicles (EU28)	17.2 million units = 19% of global motor vehicle production	2014
Passenger cars (world)	72.3 million units	2014
Passenger cars (EU28)	15.0 million units = 21% of global passenger car production	2014
REGISTRATIONS		
Motor vehicles (world)	89.3 million units	2014
Motor vehicles (EU27)	14.4 million units = 16% of global motor vehicle registrations/sales	2014
Passenger cars (world)	70.9 million units	2014
Passenger cars (EU27)	12.6 million units = 18% of global passenger car registrations/sales	2014
Diesel (EU28)	53.0%	2014
Alternative fuels (EU28)	2.7%	2014
VEHICLES IN USE		
Motor vehicles (EU28)	287.1 million units	2013
Passenger cars (EU28)	249.5 million units	2013
Motorisation rate (EU28+EFTA)	564 units per 1,000 inhabitants	2013
Average age (EU28)	9.7 years	2014
TRADE		
Exports (extra-EU28)	€124.2 billion	2014
Imports (extra-EU28)	€29.1 billion	2014
Trade balance	€95.1 billion	2014
ENVIRONMENT		
Average CO2 emissions (EU28)	123.4 g CO2/km	2014
INNOVATION		
Automobiles & parts sector	€41.5 billion	2013
TAXATION		
Fiscal income from motor vehicles (EU14)	€396 billion	2014

Figure 14: ACEA key figures on the automotive industry[23]

4.3 Low carbon energy diversification

Increasing power requirements in different transport modes leads to lesser options in terms of alternative fuels because of difficulties associated with electrification, high energy density requirements and, in applications like aviation, stringent fuel specifications. The lower the number of available fuel options to certain transport modes, the lower the number of options to decarbonise and to meet other objectives such as air quality and energy security. While this may lead to think that low carbon alternative fuels suitable for use in modes where options are limited should be used in those modes (e.g. biofuels should be used in aviation where there is no alternative to liquid fuel use in the foreseeable future), this validity of this argument will actually depend on the relative benefits of using alternative fuels in different modes (e.g. are the benefits of using biofuels in road

[23] http://www.acea.be/uploads/press_releases_files/POCKET_GUIDE_2015-2016.pdf

transport much greater than for aviation if electrification of road transport cannot be fully achieved or progresses slowly).

On the other hand, it is also argued that using certain alternative fuels in certain modes may lead to lock in and slower uptake of preferred options (e.g. use of biofuels in passenger cars or HDVs). Lock in could also result from the significant investment that would need to be made in infrastructure provision (e.g. CNG, LNG, as well as hydrogen and electric). Fuel lock-in can be prevented by maintaining optionality through stimulating research into areas that provide an alternative to the current leading alternative fuel and engine technology combination. Policy should also stimulate options that provide solutions for the longer term. This is particularly important for some of the heavy duty applications where there are currently not many alternatives foreseen, such as HDVs, waterborne and potentially aviation. For example the use of alcohols, ethers and SPFs in HDV and waterborne applications could well provide additional options relative to methane based fuels.

The added advantage of optionality is that it automatically provides a level of competition and energy diversification. Invariably developing technology for more than a single fuel will be costly for the technology developers and hence some R&I funds could be utilised to cover this.

4.3.1 Renewable fuel availability

The production of alternative fuels is outside the mandate of STRIA, however their availability is an important factor when assessing future option and therefore strategy. Biofuels in this context are considered to be advanced biofuels[24].

4.3.1.1 Biofuels (BTL, HVO, FAME, bioEthanol, bioMethanol, bioDME, bioLPG)

The consumption of biofuels in the EU has oscillated in the past few years, mainly due to legislative uncertainty and amounted to 14 Mtoe in 2015. However, when referring to the future availability of biomass feedstock to meet the demand for food/feed, industrial products and energy (including biofuels) the recurring theme is "uncertainty". On the one hand biomass supply potential is conditional on the definition of sustainability criteria and dependent on many factors (e.g productivity increases, technology development, new resources such as marine), and on the other hand, estimating future biomass demand is in any case highly complex as it depends on a great number of variables. The European Commission highlighted[25] the need for further research and analysis on whether there is sufficient supply of sustainable and cost-effective biomass feedstock for all energy uses post 2020. On the global scale, studies also highlight the great variability of estimations of future biomass potential[26]. The JRC is currently carrying out a comprehensive analysis on biomass supply and demand, identifying competition/synergies and possible trade-offs between various users.

---

[24] In line with EC communications « A policy framework for climate and energy in the period from 2020 to 2030" and "A European Strategy for Low-Emission Mobility"

[25] EC SWD(2014) 259 final: "State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU"

[26] Saygin et al. (2014). Renewable and Sustainable Energy Reviews 40, 1153–1167; Smith P.et al. 2014: Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the IPCC

The Biomass Futures Atlas[27] estimates the current bioenergy resource in Europe at a level of 314Mtoe, which under a sustainability scenario could increase to 375Mtoe by 2020 and fall slightly to 353 Mtoe by 2030. A follow up study, EC funded research project Biomass Policies, which considered additional constraints on biomass availability, indicates that the sustainable potential for energy uses could be of the order of 130Mtoe. Another study[28], also estimates that agricultural, forestry and municipal residues and wastes could represent a major sustainable resource (around 220 million tonnes, equivalent to around 95 Mtoe) and provide 16% of the transport energy needs by 2030, taking into consideration sustainability constraints. The potential, however, might lower due to constraints on the accessibility of the resource and competition for biomass from other sectors. . Currently 75% of the biomass used for energy purposes is allocated to heat production, 13% for electricity and 12% for biofuels[29]. Despite the potential for significant additional production, according to most forecasts there will not be sufficient sustainable biomass for biofuel production to cover future transport energy needs. Even more so considering that part of the additional advanced biofuel production capacity might be used to replace food- based biofuels. [30] Nonetheless the potential for fuel production is significant.

4.3.1.2 Biomethane

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

The level of total biomethane production foreseen for 2020 in the National Renewable Energy Action Plans is about 12 billion m^3 [31] (about 10Mtoe). The Green Gas Grids project[32] estimates that by 2030 methane-based fuels could contribute about 25-30 billion m^3 [33] (up to about 25Mtoe) to transport energy demand, with a 10% contribution from biomethane. Biomethane feedstock availability is subject to the same considerations as for biofuels.

4.3.1.3 Electricity

In the past years the share of renewable electricity generation has continued to increase, nuclear production has remained stable and generation from fossil fuels has fallen significantly. In 2013 half of Europe's total electricity came from low-carbon sources and the European electricity industry has made strong commitments to achieve carbon neutrality by 2050. However, looking at the current trends the European Commission has assessed that the 52% share in 2012 of carbon free gross electricity (from renewables and nuclear) could reach 58% by 2020, 66% by 2030 and 73% by 2050.

---

[27] 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

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

[29] According to AEBIOM statistical report 2015: http://www.aebiom.org/wp-content/uploads/2015/10/AEBIOM-Statistical-Report-2015_Key-Findings1.pdf

[30] EC Communication « A European Strategy for Low-Emission Mobility"

[31] Source: EBA

[32] Partners participating in the Intelligent Energy Europe Green Gas Grids Project: www.greengasgrids.eu

[33] Source: EBA

4.3.1.4 Hydrogen

Hydrogen can be produced from renewable or nuclear energy by splitting water via electrolysis or by biomethane reforming using organic matter as feedstocks, very low carbon pathways from well to wheel. A driver for hydrogen production could be the need to store electricity from intermittent renewable energy sources.

5 Research agenda

In this section we present the research and innovation needs and activities associated with fuel and powertrain combinations in different transport modes. The focus is on gaseous, alcohols and SPF fuels which would deliver benefits to Europe (see section 4). Non-technical challenges to deployment are also discussed where relevant.

5.1 R&I needs

5.1.1 LDVs

Alcohol and ether blending into gasoline is a relatively cost-effective solution and is also relevant in vehicles that are partially electrified such as hybrids and range extender vehicles. A more efficient use of alcohols, ethers and gases in spark ignition (SI) engines could be achieved by optimising injection, combustion, aftertreatment systems and their control. By substantially increasing today's blending ratios allowed in LDV petrol engines and optimising the engines for such blending, it would be possible to take full advantage of the higher octane content of alcohols and ethers. It is estimated that by increasing the blends from a 10% v/v maximum as specified in the EN228 standard to E85 it would be possible to achieve thermal efficiency improvements of around 5% or more, resulting in an equivalent decrease in CO2 emissions**.** Achieving this result would require the development of a fully dedicated and optimised high alcohol blend engine and combustion system. Further research is required to understand the extent, impact and especially control of currently non-regulated emissions such as aldehydes. A research programme led by Ford on the use of ethers (DME & OME) has recently started, but it is too early to understand the potential of these fuels for LDVs.

Similar synergies can be exploited in gas engines by using **compressed natural gas (CNG), biomethane or methane from PTL**. Direct injection in gas SI engines has the potential to further improve the TTW GHG emissions of such engines. The use of Low and High Pressure Direct Injection[34] (LPDI and HPDI) of CNG in both SI & CI gas engines can achieve higher efficiencies compared to relative incumbent CNG systems and lead to CO2 reductions by up to about 10%. Further improvements are possible in SI gas engines using lean combustion or Controlled Auto Ignition combustion systems. These advanced combustion systems could make full use of the properties of (bio)methane and leverage even larger efficiency improvements. These combustion systems also lend themselves very well for integration in hybrid applications. More cost effective and easier to package on-board storage systems are required for all gaseous fuels.

Synthetic Paraffinic Fuels are effectively a drop-in fuel, which makes them very attractive and potentially easy to adopt even into an existing fleet, but more work is required to understand how fuel properties can improve engine efficiency and reduce pollutant emissions.

---

[34] High Pressure Direct Injection. A technology developed specifically for natural gas, which injects both the alternative fuels and the small amount of diesel as pilot fuel directly into the cylinder. The technology maximises the use of alternative fuel while maintaining equal horsepower and torque characteristics

F**uel cells on alcohol, methane or SPF** potentially provide high efficient and low pollutant engines, but the technology is currently relatively immature.

Electrification through hybridisation will have an impact on engine size and consequently on the type of engine and its fuel compatibility. A system approach is required for the development of such powertrains. Increased electric propulsion power does mean that engines can be further optimised to operate more efficiently and more cleanly within a smaller speed / load operating window as well as have lower transient requirements.

Please note that wherever possible we have aligned the challenges (-) and opportunities (+) with the research and innovation needs in the tables below.

Table 12 - LDV summary table of R&I needs

LDV				
Fuel category	**Fuel**	**Powertrain**	**Challenges(-) & opportunities(+)**	**R & I needs**
Natural gas	Compressed natural gas, biomethane or methane (CNG)	SI engines optimised for gas operation	- Methane leakage	- Measurement of evaporative emissions to check if there is a problem, and research on control measures if necessary
			+ Potential for efficiency improvements in Low and High Pressure Direct Injection of CNG relative to incumbent CNG systems + Further engine thermal efficiency improvements of around 5% through synergies of high octane with downsizing in real world driving conditions + Further reduction of tail pipe pollutant emissions due to lower engine out emissions. + On-board storage improvements through conformable, cheaper, lightweight solutions	+ Dedicated gas LPDI and HPDI systems + More dedicated CNG engine and combustion system designs + New components for high efficiency and performance SI engines, such as direct injectors, electronic regulators, gas quality sensors and control strategies + Better combustion and after treatment control strategies + Optimised TWC chemistries to reduce tailpipe pollutants and methane further + Conformable CNG cylinders development and vehicle integration
		SI lean	- Ignition system and control to robustly initiate combustion and maintain good combustion stability at very lean conditions to ensure low engine out NOx emissions - Appropriate and cost-effective aftertreatment systems to meet regulation - Effective air handling and load control	- Development of advanced ignitions systems such as fully controllable multiple spark ignition, corona, plasma etc - Dedicated lean burn gas engines with advanced aftertreatment systems - Fast response and variable air handling systems such as electric superchargers with appropriate control systems to ensure good driveability
			+ Significantly increase the engine thermal efficiency and therefore CO2 emissions estimated at 10-20% relative to incumbent CNG systems + Synergies with increased electrification	+Dedicated combustion, fuelling and air handling system design + Fully optimise and integrate the engine with the electric propulsion system (hybridisation, range extender etc)
Liquid Petroleum Gas	LPG, BioLPG	SI	+ High Pressure Direct Injection of LPG	+ Vehicle with a dedicated High Pressure Direct Injection spark ignition engine running on LPG/bioLPG (with optimized compression ratio, injection strategies, use of EGR and any other measure directed to improve engine efficiency such as

			+ Light weighting of the on-board fuel storage equipment	lean operation) + Injection system for LPG/bioLPG direct injection which prevents vapour lock under hot conditions + Light weight fuel tank for LPG/bioLPG in-vehicle storage with a shape suitable to be integrated as a conventional tank (e. g. under the vehicle trunk)
Esters, ethers & **alcohols**	Methanol	FC	+ Potential to have FC efficiencies while using liquid fuels making implementation much simpler than hydrogen	+ Fuel cells using low carbon synthetic and fossil fuels
Esters, ethers & **alcohols**	Ethanol, methanol, butanol and other alcohols or blends	SI	- Mature technology when within EN228. No issues reported - Largely mature technology when used blended with gasoline up to E85 equivalent -Gasoline substitution worsens current unbalance + Further engine thermal efficiency improvements of around 5% through synergies of high octane with downsizing in real world driving conditions when optimised for higher blends levels such as E85. (Not Flex Fuel Vehicle) + Thermal efficiency improvement through lean combustion with appropriate NOx control as main powertrain or for hybrid application	+ Dedicated fully optimised high alcohol blend engine and combustion system designs +Improved combustion and after treatment control strategies (incl. for currently non-regulated emissions such as aldehydes) + Fully optimise and integrate the engine with the electric propulsion system (hybridisation, range extender engine) + Bi-fuel SI vehicles (octane on demand) using higher octane biofuels in conjunction with lower octane carbon footprint fossil or synthetic fuels

5.1.2 HDVs

Methane based gases in either compressed (CNG) or liquefied (LNG) form are currently considered as the main alternative fuel for the HDV sector (which is powered by CI engines). Dual fuel CI engines (engines capable of running on diesel or CNG/LPG with diesel pilot in this case), however, do not currently meet Euro VI emission limits. Significant research effort into advanced injection systems and /or aftertreatment systems that can operate under low temperature conditions is required to overcome this issue. There is also potential for a better utilisation of these alternative fuels leading to increased engine efficiency through the development of high pressure direct injection (HPDI). HPDI systems are under development and could deliver dual fuel engines with a high substitution rate for diesel (90%) and characteristics similar to current diesel engines including efficiency. Methane tailpipe emissions, which currently exceed EURO VI limits, are being addressed, but remain a concern for the rest of the fuel chain. Direct injection in SI gas engines could improve efficiency and tank-to-wheel (TTW) GHG emissions of such engines, approaching CI engine technology, while meeting EURO VI emissions limits due to the possibility of significantly reducing methane slip.

Engine technology is currently commercially available for **DME and ED95** combustion systems, which provide alternatives to CNG/LNG technology. While these technologies meet EURO VI emission limits and have efficiency similar to diesel engines, further research into engine efficiency improvement, pollutant control and end-fuel specifications could yield further improvements. The emission of currently non-regulated emissions such as aldehydes needs further research.

Similarly to LDVs, **Synthetic Paraffinic Fuels** represent a drop-in solution which could be adopted by the existing fleet, however their cost and benefits in terms of improved efficiencies and reduced pollutants need to be further researched and understood.

In the longer term **fuel cells fuelled by alcohols or other alternative fuels** could be of interest, also for ancillary power supply.

Another area for R&I is the development of high efficiency, low pollutant and low cost engines for use in **hybridisation / range extender applications**.

Table 13 - HDV summary table of R&I needs

HDV

Fuel category	Fuel	Powertrain	Challenges(-) & opportunities(+)	R & I needs
Natural gas	Compressed of liquefied natural gas, biomethane or methane (CNG, LNG)	SI engines optimised for gas operation	+Mature technology that is commercially available - Risk of methane slip / leakage from the fuelling system	- Specific hardware and control strategies to limit evaporative methane emissions from the fuel system and crankcase
			+ Increase engine thermal efficiency, but unlikely to reach current diesel engine levels + Further reduction of tail pipe pollutant emissions due to lower engine out emissions + On-board storage improvements through conformable, cheaper, lightweight solutions	+ Dedicated CNG/LNG engine and combustion system designs + Better combustion and after treatment control strategies + Optimised TWC chemistries to reduce tailpipe pollutants and methane further + New components for high efficiency and performance SI engines, such as direct injectors, electronic regulators, gas quality sensors and control strategies + Cheaper and more space efficient (e.g. conformable) LNG tanks development and vehicle integration
		SI lean	- Ignition system and control to robustly initiate combustion and maintain good combustion stability at very lean conditions to ensure low engine out NOx emissions - Appropriate and cost-effective aftertreatment systems to meet regulation - Effective air handling and load control	- Advanced ignitions systems such as fully controllable multiple spark ignition, corona, plasma, etc - Advanced aftertreatment systems for dedicated lean burn gas engines - Fast response and variable air handling systems such as electric superchargers with appropriate control systems to ensure good driveability
			+ Significantly increase the engine thermal efficiency of about 10-20% relative to SI gas engine, reaching diesel levels of efficiency + Potentially well suited to being combined with increased electric propulsion (Plug in hybrid, range extender)	+Dedicated combustion, fuelling and air handling system design + Fully optimise and integrate the engine with the electric propulsion system (Plug in hybrid, range extender)
		CI - Dual Fuel	- Methane tailpipe emissions exceed EURO VI limits	- Low CH4 combustion system or CH4 catalysis.

			currently with HPDI in development to solve this issue - Methane catalysis at low temperatures experienced at regulated test procedures	
			+ HPDI technology + Multifuel capabilities to bridge fuel transition + Further thermal efficiency improvements + Increased gas replacement factors + On-board storage improvements through conformable, cheaper, lightweight solutions	+ Advanced fuel injection systems (incl. high pressure direct injection – HPDI), regulation components, gas quality sensing and control strategies + Advanced aftertreatment systems at competitive cost + Cheaper and more space efficient (e.g. conformable) zero-vent LNG tanks development and vehicle integration”
Liquid Petroleum Gas	LPG, BioLPG	SI	+ Improved engine efficiency through dedicated engine design with direct injection systems + Further reduction of tail pipe pollutant emissions due to lower engine out emissions + Significant thermal efficiency through lean combustion reaching diesel levels with appropriate NOx control as main powertrain or for hybrid application + On-board storage improvements through conformable, cheaper, lightweight solutions	+ Vehicle with a dedicated direct injection spark ignition engine running on LPG/bioLPG (with optimized compression ratio, injection strategies, use of EGR and any other measure directed to improve engine efficiency such as lean operation) + Injection system for LPG/bioLPG direct injection which prevents vapour lock under hot conditions + Advanced aftertreatment chemistries and systems at competitive cost + Integration of LPG/bioLPG engine in a hybrid vehicle + Light weight fuel tank for LPG/bioLPG in-vehicle storage with a shape suitable to be integrated as a conventional tank (e. g. under the vehicle trunk)
Esters, **ethers** & alcohols	DME, OME	CI (incl. LTC etc.)	- DME engines are mature EURO VI technology, commercially available through Volvo	
			+ Lack of PM allows further NOx reduction and / or improved fuel economy + Dedicated fuel injection technology and control might allow further thermal efficiency improvements and pollutant emission reduction + On-board storage improvements through conformable, cheaper, lightweight solutions	+ Dedicated and optimised DME combustion, fuel, control and aftertreatment systems with the aim to even further improve TTW GHG and pollutant emissions + Light weight fuel tank for DME (similar to LPG) in-vehicle storage with a shape suitable to be integrated as a conventional tank (e. g. under the vehicle trunk)

Esters, ethers & **alcohols**	Ethanol, methanol, butanol and other alcohols or blends	SI, SI lean	- Early stage research at MIT, Ghent University - Driveability and emissions control - Potential for non-regulated aldehyde emissions	+ Significant potential was demonstrated during early testing. Further more detailed testing is required to understand the detailed R&I needs
			+ Engine thermal efficiency matching or exceeding that of CI diesel engines throughout the operating area + Reduction of tail pipe NOx and PM emissions + Dedicated fuel injection technology and control might allow further thermal efficiency improvements and pollutant emission reduction + Potentially well suited to being combined with increased electric propulsion (PHEV, Range Extender)	+ Dedicated and optimised alcohol combustion, fuel, control and aftertreatment systems with the aim to even further improve TTW GHG and pollutant emissions. + Lean SI system development with specific advanced ignition systems, aftertreatment and control systems + Develop high efficiency, low pollutant and low cost engines for use in hybridisation / Range Extender
Esters, ethers & **alcohols**	Ethanol, Methanol	CI (incl. low temperature combustion systems)	- Ethanol with an ignition improver (ED95) is a mature EURO VI technology for HDV applications (Scania)	- Suitability of other alcohols. Methanol with an ignition improver (MD95) is under investigation at VTT
			+ Potential to demonstrate an optimised alcohol based fuel with appropriate additives in CI engine technology + Reduction of tail pipe pollutant emissions + A single liquid fuel diesel alternative that makes the infrastructure issue much easier	+ Dedicated and optimised alcohol (with an ignition enhancer) combustion, fuel, control and aftertreatment systems with the aim to even further improve TTW GHG and pollutant emissions
	Methanol	CI Dual Fuel	- Currently very immature technology in HDV, but principle demonstrated and commercialised in shipping and in principle similar to NG Dual Fuel - Potential corrosion issues - Potential for non-regulated aldehyde emissions	- Significant R&I requirements as this technology is immature - Need for research to assess suitability of this fuel and technology for HDV sector - Assess corrosion issue and develop new materials / additives - Assess the scale of aldehyde emissions & aftertreatment option
			+ Dedicated fuel injection technology (HDPI) and control might allow further thermal efficiency improvements + Multifuel capabilities to bridge fuel transition + Engine thermal efficiency matching or exceeding that of CI diesel engines throughout the operating area + Further reduction of tail pipe pollutant emissions due to	+ Optimised injection equipment for alcohol dual fuel applications + Optimised combustion, aftertreatment & control systems

			lower engine out emissions. + Lack of engine out PM allows further NOx reduction and / or improved fuel economy	
SPF	SPF	Other	+ To address the EU imbalance between gasoline and diesel demand.	+ Naphtha or other higher volatility/ less processed fuels in compression ignition engines using low temperature combustion for improved efficiency with lower emissions and WTW CO2 reduction + Low temperature combustion in CI using higher volatility synthetic/low carbon e.g. paraffinic fuels for improved efficiency and reduced emissions

5.1.3 Rail

The use of alternative fuels in ICE technology in rail is considered for those routes where overhead line electrification is not commercially feasible and diesel engines are used. The rail sector is currently not a technology leader in ICE technology and fleet turnover is generally slow. As a consequence the sector relies heavily on adapted engines and other technology originally developed for the on and off-road HDV sector and hence most of the HDV considerations would also apply here.

The main alternatives considered are **LNG** and the increased use of **biodiesel and SPFs** (e.g. HVO). The uptake of LNG as an option, requires the engineering of new locomotives for dedicated LNG engine or dual-fuel engines since this option is not suitable for existing locomotive retrofitting. Furthermore significant efforts are required to roll out dedicated and optimised combustions systems for these fuel types as well the required aftertreatment systems meeting NRMM stage V.

The use of **biodiesel** in engines with blending up to 20% (B20) is considered a mature technology, and such blending does not require significant engine modifications. This option has the merit of decreasing soot emissions, but may increase fuel consumption and NOX emissions, requiring combustion control and aftertreatment systems.

Increased levels of vehicle **electrification** enable engines to be optimised for one or a small number of operating conditions where it is most efficient as is the case in range extender vehicles for example. Additional efficiency improvements can then be leveraged by utilising the unique properties such as octane level of alcohol and methane based fuels.

Table 14 - Rail summary table of R&I needs

Rail

Fuel category	Fuel	Powertrain	Challenges(-) & opportunities(+)	R & I needs
Esters	Biodiesel	CI	- Cold-weather characteristics not suitable for low temperature operation without fuel-line heaters. - Current knowledge shows an increase of NOx when using biodiesel.	- Advanced combustion control and aftertreatment systems
			+ Mature technology (US) - The use of B20 in railway engines is acceptable without requiring significant engine modifications. + B20 decreases the hydrocarbon and soot emissions, but may increase the fuel consumption (engine type, tuning level).	+ Combining technologies (bi-mode trains) to improve fuel combustion efficiency and pollution reduction. + Advanced combustion technologies for managing NOx released during the combustion.
Natural Gas / alcohol	LNG / methanol	CI-DF	- Not suitable for existing locomotive retrofitting - Safety issues related to methane leakage	
			+ HPDI technology developed in shipping and trucking for both gas and alcohols would be equally suitable for rail	+ Develop high energy efficiency locomotive + Engineering new locomotive for dedicated LNG-gas engine or dual-fuel engines + Combining propulsion system for energy saving + Optimise the combustion system to reduce the fuel consumption (automatic controlling devices)

5.1.4 Waterborne

Large scale adoption of alternative fuels within the waterborne sector offers the possibility of significant reductions in airborne pollutants compared to the heavy fuel oils used. The two main alternative fuels that are currently considered for waterborne applications are **methane and methanol**. Both are currently commercially available and mainly used in dual fuel applications with gas oil used as a pilot injection to initiate combustion. Both methane-based fuels (LNG/LBG/PTL) and methanol could significantly reduce SOx and PM emissions in particular, as well as NOx emissions. The use of methanol could reduce NOx emissions by up to 60%, but not down to Tier-III level. Further research should be focussed on increasing the methanol / gas substitution rates respectively, engine efficiency and further reducing pollutant emissions, including eliminating methane slip. R&I on dedicated high efficiency lean combustion engines for either methane or methanol based fuels can potentially provide higher efficiency, low pollutant and GHG emission solutions.

Methane slip throughout the fuels chain is a concern for methane based fuels that warrants further research. Technologies for methane slip reduction need to be incorporated in new ship designs. Exhaust gas recirculation (which improves combustion stability), the use of aftertreatment systems with methane oxidation catalysts, or high-pressure direct injection are techniques able to reduce methane slip.

In the longer term fuel cells fuelled by alcohol, LNG/LBG/PTL or other alternative fuels could be of interest, for both propulsion and ancillary power supply.

Better storage and handling solutions and bunkering logistics are required for LNG and methanol. Wide scale uptake of either fuel is hampered by the limited (global) bunkering provisions.

Table 15 - Waterborne summary table of R&I needs

Waterborne Transport				
Fuel category	**Fuel**	**Powertrain**	**Challenges(-) & opportunities(+)**	**R & I needs**
Alcohols	Methanol	CI-DF	- Immiscible with marine fuels – cannot be used as blends. + Reduces emissions of PM by >80% and SOx by >90% depending on the substitution rate + Already used as main fuel in an adapted marine diesel engine with StenaLine. + Reduces NOx emissions by up to about 60% + Methanol and solid oxide fuel cell (SOFC) system for ancillary power.	+ Develop engines & injection equipment allowing increased methanol (and other alcohols) substitution rates or have dedicated methanol engine technology that meets / exceeds current marine oil engine efficiencies at low CAPEX cost and low noxious emissions + Advanced aftertreatment systems (NOx) at competitive cost + Future research activities on larger methanol-fuel cells on marine vessels. + Tests for assessment of environmental impacts of methanol and SOFC technology for shipping.
Natural gas	LNG	SI	- Fuel availability, safety issues for on-board fuel storage, handling systems. - Possibility of abnormal combustion (methane slip) – sensitive to gas composition + Waterborne engines using low pressure LNG have emissions below NOx limit (IMO Tier III) without use of exhaust gas treatment system + Possibility to use the cooling effect of LNG vaporisation for refrigeration of foods (e.g. fish boats), air conditioning on-board, and other cooling effect carries	+ New engine design for: load efficiency optimisation, reduction of methane slip, adaptation to variable gas composition. + Emission control and energy efficiency measures for ships in the port area. + Waste heat recovery from propulsion engine for overall fuel consumption management on ship. + Investigation on ultrafine PM + Fuel handling and storage (onboard and shore): better storage solution (space, cost), bunkering logistics.
		CI-DF	- Sensitive to gas composition - Higher NOx emissions than the lean burn type (SI). + Fuel flexible engines - able to switch between fuels in	+ Improvement of energy efficiency of large vessels for coastal and seagoing vessels (increase propulsion efficiency – combined electric propulsion, integrated propeller-rudder configuration).

			different sailing regions or when some abnormal combustion or leakages occur. Less dependence on the availability of LNG bunkering facilities when sealing in different regions.	+ Advanced injection (HPDI) and combustion systems for greater efficiency + Advanced optimised cylinder lubrication systems. + Advanced catalyst system for aftertreatment (NOx) at competitive cost + Investigation on the impact of switching fuel on emissions level and engine components. + Numerical models for evaluating case by case the integration of energy efficiency systems in new ships designs. + Developments in sensors, condition assessment and adaptive control methods, materials tribology and lubrication improvements + Waste heat recovery from propulsion engine for overall fuel consumption management on ship.

5.1.5 Aviation

Aviation strongly relies on energy dense fuels. While radical redesign of aviation powertrains is progressing, the sector is expected to remain highly dependent on drop-in fuels for at least the next 30 years. Synthetic Paraffinic Fuels (SPFs) currently seem the most feasible alternative fuel for the foreseeable future. Various routes to synthetic kerosene are already technically available for commercial aviation and up to other 20 are currently waiting to be tested and approved for use. Important areas of research with regards to the use of SPFs in aviation include assessment of the impact on engine components, understanding blending limits and optima, and impact on pollutant emissions. In terms of energy efficiency, the gains that can be expected from using drop-in fuels are minimal (~2%), but there is an interesting potential for reduction of non-volatile particulate matter (nvPM) (up to 60% reduction in mass and 40% on PM number with a 50/50 blend[35]). Research is also focused on understanding the lower limits for some aromatics species and sulphur for providing optimal performance while reducing SOx and PM emissions. The effect of different blend levels of drop-in fuels on parameters like combustion temperature, efficiency, unburned hydrocarbons and black carbon are a subject of research, and could lead to different high altitude effects compared to conventional kerosene. Further research on the SPFs is needed in relation to chemical composition, allowable and optimal blending levels, and impact on pollutant emissions. Radical aircraft redesign could lead to the consideration of liquefied methane and hydrogen as fuels in the longer term.

[35] EC funded ITAKA project

Table 16 - Aviation summary table of R&I needs

Aviation				
Fuel category	**Fuel**	**Powertrain**	**Challenges(-) & opportunities(+)**	**R & I needs**
SPF	FT-SPK, HEFA-SPK, FT-SKA	Turbofan	- Unknown real blend limits, current limit related with aromatics and sulphur content + Similar composition to incumbent + Mature technology once blended up to 50% v + Blend ratio likely to be enlarged with better knowledge + Lower pollutants (PMs up to -60%, and S) + Potential (lower?) climate effect at altitude	+to know what is maximum blend limit, particularly with regards to minimum aromatics and sulphur content +need to know effects on maintenance operations (i.e. in flight water generation) with long term use +to know the effects on key emissions varying properties of the fuel, engines, operations and atmospheric conditions to better define the extent of the benefits of the use. +Integrated, fuel-centric research, investigating the effects of fuel composition on operations and emissions, where fuel is varied for otherwise identical conditions, and the effects identified. Such research should include fuels outside the current experience base for fossil fuels, to identify risks and opportunities +Support testing at ASTM for enabling more alternatives
SPF	SIP	Turbofan	- blend limits, probably cannot go higher - fuel composition different to incumbent + Mature technology once blended up to 10% v + Lower pollutants (PMs up to -60%, and S) + Potential lower NOx emissions with better design + Potential (lower?) climate effect at altitude	+Integrated, fuel-centric research, investigating the effects of fuel composition on operations and emissions, where fuel is varied for otherwise identical conditions, and the effects identified. Such research should include fuels outside the current experience base for fossil fuels, to identify risks and opportunities +Support testing at ASTM for enabling more alternatives
SPF	ATJ	Turbofan	- blend limited by fuel gauging system performance - fuel composition different to incumbent + Mature technology once blended up to 30% v + Lower pollutants (PMs up to -60%, and S) + Potential (lower?) climate effect at altitude	+Integrated, fuel-centric research, investigating the effects of fuel composition on operations and emissions, where fuel is varied for otherwise identical conditions, and the effects identified. Such research should include fuels outside the current experience base for fossil fuels, to identify risks and opportunities Support testing at ASTM for enabling more alternatives
SPF	HEFA+	Turbofan	- Fit for purpose not certified - max (foreseen) blend 10% v - Mature (fuel) technology + Lower pollutants (PMs and S) + Potential (lower?) climate effect at altitude	+Needs to better understand the blend limits and the properties for production and distribution +Integrated, fuel-centric research, investigating the effects of fuel composition on operations and emissions, where fuel is varied for otherwise identical conditions, and the effects identified. Such research should include fuels outside the current experience base for fossil fuels, to identify risks and opportunities

				+ Support testing at ASTM for enabling more alternatives
LNG	LNG	Turbofan	- not drop-in, volume/weight/energy ratio requires different aircrafts, logistics facilities - Increased water vapour emission by 40% (potential climate impact) [AHEAD] - uncertain climate effect (balance) at altitude	+ Breakthrough research on airframe and combination with electrification
			+ Decrease of CO_2 by 25% [AHEAD] + Decrease of NOx by 80% [AHEAD] + Zero PM emissions [AHEAD] + better thermal efficiency	

5.2 Implementation plan

Reducing GHG emissions in transportation consists of two main elements, namely:

1. The availability of cost-effective sustainable low carbon alternative energy / fuels (well-to-tank - WTT)
2. Improved efficiency in real world utilisation (tank-to-wheel - TTW)

This report deals with the potential impact of alternative fuels on the latter, as well as their potential impact on emissions affecting air quality. Decarbonisation will depend on the full well-to-wheel implications of alternative fuel use, and will need to rely on low carbon and renewable fuels, while alternative fossil-derived fuels could help address in the interim air quality and energy diversification issues.

Figure 15 provides a possible high level timeline for implementation of promising alternative fuel and powertrain combinations. The R&I needs for each transport sector supporting effective implementation are summarised below and detailed in Table 12 to Table 16.

A number of alternative fuel options could be deployed in each mode with benefits in terms of optionality and energy diversification. LDVs and rail also have the option of increased electrified propulsion systems through on-board storage of electricity or hydrogen and overhead electrification lines, which are dealt with in the STRIA on electric mobility.

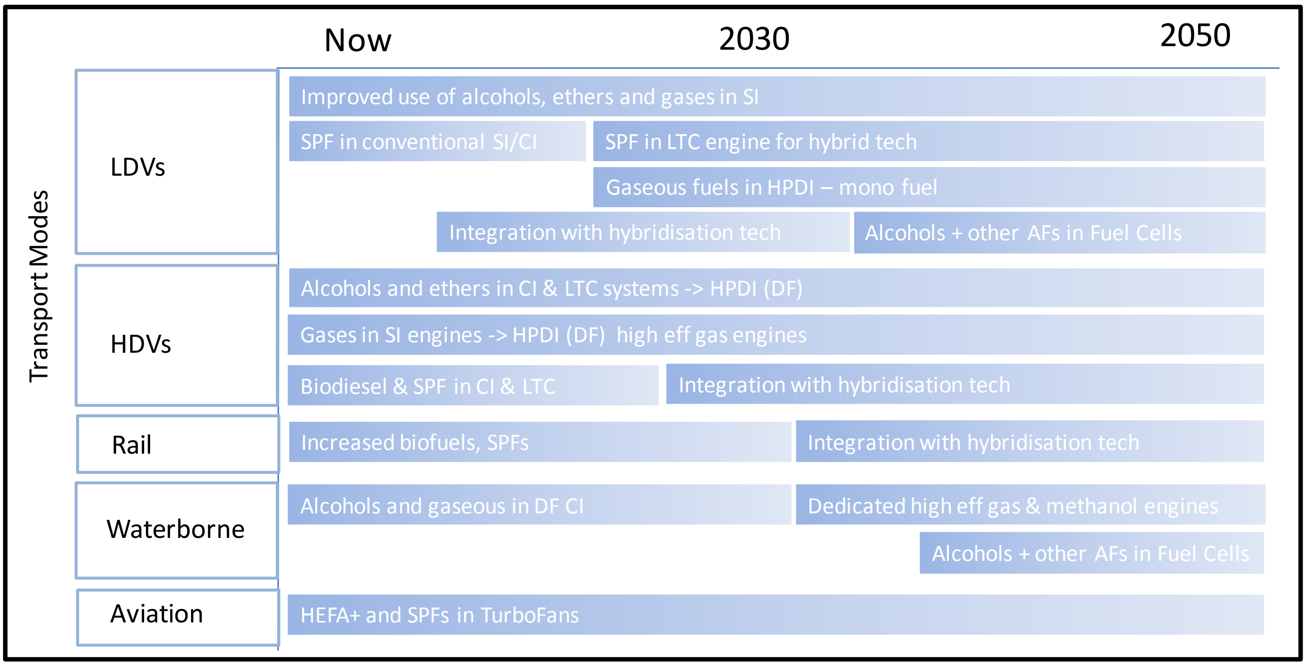

Figure 15 - Overview and timescales of most promising alternative fuel options

5.3 Synthesis of R&I agenda

The main alternative fuels are gases, alcohols, ethers and drop-in SPFs with specific technology R&I requirements highlighted in the tables and text in section 5.1 for each transport mode. The rest of this section provides a synthesis of the R&I agenda in support of the implementation plan above.

LDVs

Increase the uptake of alcohols, ethers and gases in spark ignition (SI) engines (taking into consideration their potential for GHG savings), while improving their use by optimising injection, combustion, aftertreatment systems and their control. For compression ignition (CI) engines the uptake of more biodiesel and especially SPF (again taking into consideration their potential for GHG savings) would benefit from optimisation of the engine and related technology.

Direct injection in gas SI engines has the potential to further improve the TTW GHG emissions of such engines. Both SI & CI gas engines can achieve higher efficiency combustion systems, such as lean combustion, controlled auto-ignition (CAI) for SI engines and homogeneous charge compression ignition (HCCI) and all manner of low temperature combustion (LTC) systems for CI engines. Implementation of such systems would significantly benefit from narrower fuel specifications, which alternative fuels could provide.

Furthermore, these combustion systems tend to be best suited to and most efficient at a narrower operating window both in terms of speed/load as well as their transient capability. Increased levels of electrification can facilitate this by effectively filling in the operating window gaps. A strong R&I focus on optimisation of the complete system with increased levels of electrification is therefore required.

In the longer term fuel cells fuelled by alcohols or other alternative fuels could be of interest.

HDVs

Alcohol and ether based CI combustion systems are commercially available, but not widespread in part due to lack of infrastructure. There is further development potential in the better utilisation of these fuels with a particular focus on high efficiency high pressure direct injection (HPDI) dual fuel systems as well as LTC systems.

Direct injection in SI gas engines could improve efficiency and tank-to-wheel (TTW) GHG emissions of such engines, approaching CI engine technology, while meeting EURO VI emissions limits due to the possibility of significantly reducing methane slip.

High efficiency combustion systems that operate in a narrower window both in terms of speed/load as well as their transient capability could be developed for HDVs for lighter duty cycles i.e. shorter distances, lower speeds and lower carrying capacity. Increased levels of electrification can facilitate this by effectively filling in the operating window gaps. A strong R&I focus on optimisation of the complete system with increased levels of electrification is therefore required for these vehicles.

In the longer term fuel cells fuelled by alcohols or other alternative fuels could be of interest, also for ancillary power supply.

For road transport the immediate R&I needs are summarised comprehensively in ERTRAC's "Energy carriers for Powertrains" [6]

Rail

Where overhead line electrification is not commercially feasible the rail sector could benefit from the increased use of blended biofuels and SPFs. Typically this sector relies heavily on adapted engines and other technology originally developed for the on and off-road HDV sector and hence most of the HDV considerations above would also apply here, including gas engines that could be of interest in future locomotives. The availability of an (overhead) charging infrastructure and well-known duty-cycles suggests that the interaction between ICE and electrification technology is particular promising. In the longer term fuel cells fuelled by alcohol, LNG/LBG/PTL or other alternative fuels could be of interest.

Waterborne

Large scale adoption of alternative fuels within the waterborne sector offers the possibility of significant reductions in airborne pollutants compared to heavy fuel oils. Methane-based gas (LNG/LBG/PTL) and methanol in dual fuel applications are commercially available and would be adopted more widely if greater fuelling infrastructure were available, and supply chains, storage and engines could be further optimised to eliminate methane slip, improve efficiency and emissions.

High efficiency combustion systems that operate on a single fuel in a narrower window both in terms of speed/load as well as their transient capability could be developed for some ship engines.

In the longer term fuel cells fuelled by alcohol, LNG/LBG/PTL or other alternative fuels could be of interest, for both propulsion and ancillary power supply.

Aviation

SPFs are the most feasible alternative fuel for the foreseeable future for aviation. Various end-fuels are under consideration, and research will focus on assessing impact on engine components, understanding blending limits and optima, and impact on pollutant emissions.

5.3.1 Roles and resources

The automotive industry and its suppliers are major investors in innovation, to the tune of around 40 billion Euros according to ACEA[36]. Much innovation and related spending has gone into improving vehicle efficiency to meet lower vehicle CO2 emissions limits.

Alternative fuels should play a major role in reducing CO2 emissions from transport by substituting fossil fuels, but the role they can play in reducing tailpipe CO2 emissions by allowing engine efficiency improvements and more efficient hybridisation also need to be recognised for these benefits to be realised. Recognising and realising these benefits requires a greater interplay between fuel suppliers and the automotive industry, so that emissions reduction from fuel use and from vehicle operation are no longer seen as separate and the synergies between the two are exploited.

[36] http://www.acea.be/uploads/press_releases_files/POCKET_GUIDE_2015-2016.pdf

Integration will be a feature of future research and innovation, stressing the importance of cross-industry and cross-country collaborations. European Framework programmes are therefore ever more relevant in this context. So, is also the continued development of industry research roadmaps that specifically incorporate alternative fuel and vehicle interactions. Harmonisation too has a role to play in effectively delivering a clean transport system in Europe, for example through fuel specifications that enable higher levels of alternative fuels to be delivered to the market. The European Commission and cross-industry groups will continue to be instrumental in this area. Research will however also need to deliver technologies which are able to deliver best results under variable conditions e.g. varying blend levels across Europe.

Policy will need to play an important role in steering the research towards meeting specific environmental objectives, as it has successfully done in the case of vehicle CO2 emissions and HDV noxious emissions. So, the role of policy will be critical in sending signals to the market about the expected importance of alternative fuels. This will drive the private sector to allocate research resources to alternative fuels, which will be complemented by national and European funding to support innovation in the area.

6 References

[1] DG TAXUD (2015) "Excise duty tables". Available at: http://ec.europa.eu/taxation_customs/index_en.htm#

[2] COWI for DG MOVE (2015) "State of the Art on Alternative Fuels Transport Systems in the European Union". Available at: http://ec.europa.eu/transport/themes/urban/studies/doc/2015-07-alter-fuels-transport-syst-in-eu.pdf

[3] IEA (2014) "Ethanol and biodiesel consumption in road transport by region in the New Policies Scenario".

[4] EurObserv'ER (2015) "Biofuels barometer". Available at: http://www.eurobserv-er.org/category/all-biofuels-barometers/

[5] EC (2015) "EU energy in figures - Statistical pocket book 2015"

[6] ERTRAC "Energy carriers for powertrains", 27/2/2014, http://www.ertrac.org/uploads/documentsearch/id32/2014-03-12_Roadmap_Energy_Carriers_for_Powertrains.pdf

[7] ERTRAC "Future light and heavy duty ICE powertrain technologies", 9/6/2016, http://www.ertrac.org/uploads/documentsearch/id42/2016-06-09_Future%20ICE_Powertrain_Technologies_final.pdf

[8] EMSA (2015) "Study on the use of ethyl and methyl alcohol as alternative fuels in shipping". Available at: http://www.emsa.europa.eu/news-a-press-centre/external-news/item/2726-study-on-the-use-of-ethyl-and-methyl-alcohol-as-alternative-fuels-in-shipping.html

[9] European biofuels (2014) "European Biofuels Technology Platform (EBTP) - - an Overview". Available at: http://biofuelstp.eu/overview.html

[10] EC (2013) "Clean Power for Transport: a European alternative fuels strategy". Available at: http://eur-lex.europa.eu

[11] IEA (2015) "Railway Handbook 2015". Available at: http://www.iea.org/topics/transport/publications/railwayhandbook2015/

[12] EEA (2013) "EMEP/EEA emission inventory guidebook 2013 – Navigation". Available at: www.eea.europa.eu/publications

[13] Clean North Sea Shipping Project (2013) "LNG fuelled ships for clean air in harbours Greener Shipping in the Baltic Sea". Available at: http://cnss.no/

[14] Clean North Sea Shipping Project "Cleanship – final report". Available at: http://www.clean-baltic-sea-shipping.com/uploads/files/CLEANSHIP_final_report_for_download.pdf

[15] DNV GL – Maritime (2016) "Engines for gas-fuelled ships". Available at: https://www.dnvgl.com/maritime/

[16] DNV GL – Maritime (2014) “LNG as ship fuel. Alternative fuels for shipping”. Available at: https://www.dnvgl.com/maritime/

[17] TEN-T Projects (2013) “LNG infrastructure of filling stations and deployment in ships”. Available at: https://ec.europa.eu/inea/en/ten-t/ten-t-projects/projects-by-country/multi-country/2010-eu-21112-s

[18] EU (2016) “Significant LNG fuelled Ships”. Available at: https://lngforshipping.eu

[19] EC (2015) “Consultation on an EU strategy for LNG and gas storage”. Available at: https://ec.europa.eu/energy

[20] JRC (2016) “Alternative Fuels for Waterborne and Inland Waterways”. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC100405/inland%20and%20Waterborne%20waterways%20exploratory%20work%20on%20alternative%20fuels_kamaljit%20moirangthem_final.pdf

[21] EC (2016) “Reducing emissions from the shipping sector”. Available at: http://ec.europa.eu/clima/policies/transport/shipping/index_en.htm

[22] EPA (2014) “Reducing Emissions from Non-road Diesel Engines”. Available at: http://www.epa.nsw.gov.au/

[23] UIC (2012) “Moving towards sustainable mobility”. Available at: http://www.uic.org

[24] Railway Technology (2013) “Hydrail and LNG: the future of railway propulsion”. Available at: http://www.railway-technology.com/

[25] Railway Technology (2013) “Russian railways: connecting a growing economy”. Available at: http://www.railway-technology.com/

[26] IMO (2015) “Third IMO GHG Study 2014”. Available at: http://www.imo.org/

[27] IEA (2015) “CO2 Emissions From Fuel Combustion Highlights 2015”. Available at: https://www.iea.org/publications/freepublications/publication/co2-emissions-from-fuel-combustion-highlights-2015.html

[28] EMSA (2016) “Study on the use of ethyl and methyl alcohol as alternative fuels in shipping”. Available at: http://www.emsa.europa.eu/news-a-press-centre/external-news/item/2726-study-on-the-use-of-ethyl-and-methyl-alcohol-as-alternative-fuels-in-shipping.html

[29] IEA (2013) “Alternative Fuels for Marine Applications”. Available at: http://www.iea-amf.org/app/webroot/files/file/Annex%20Reports/AMF_Annex_41.pdf

[30] ATAG (2012) “A sustainable flightpath towards reducing emissions”. Available at: http://www.atag.org/component/downloads/downloads/203.html

[31] ICAO (2013) “ICAO environmental report 2013. Aviation and climate change”. Available at: http://cfapp.icao.int/Environmental-Report-2013/files/assets/common/downloads/ICAO_2013_Environmental_Report.pdf

[32] Steve Csonka (2016) "CAAFI – CORE-JetFuel Cooperation Workshop". Available at: www.core-jetfuel.eu

[33] ASTM (2016) "ASTM D7566-16, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons". Available at: http://www.astm.org/Standards/D7566.htm

[34] ITAKA project (2016) "Press release. ITAKA provides sustainable fuel for worldwide's first biojet supply via hydrant system at Oslo Airport". Available at: http://www.itaka-project.eu/Shared%20Documents/20160122_ITAKA_airportusage_start.pdf

[35] Greenaironline (2016) "United begins regular use of commercial-scale volumes of AltAir's renewable jet biofuel on flights from LAX". Available at: http://www.greenaironline.com/news.php?viewStory=2208

[36] Ecofys (2016) "Accounting methods for biojet fuel. Final report". Available at: http://www.ecofys.com/files/files/ecofys-2015-accounting-methods-for-biojet-fuel.pdf

[37] EU Biofuels Flightpath (2016) "2 million tons per year: A performing biofuels supply chain for EU aviation". Available at: https://ec.europa.eu/energy/sites/ener/files/20130911_a_performing_biofuels_supply_chain.pdf

[38] Road fuel demand in the EU, https://www.fuelseurope.eu/uploads/images/update2016/Graphs_FUELS_EUROPE%20_2016_WEB%20(9)_756.jpg

[39] EC communication (2014), A policy framework for climate and energy in the period from 2020 to 2030, Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0015&from=EN

[40] Methanol as a marine fuel report, FCBI energy (2015). Available at: http://methanol.org/getdoc/a9af8c29-e199-4854-b1c7-4e869991aaa7/FCBI-Methanol-Marine-Fuel-Report-Final.aspx

7 Appendix

7.1 Table of acronyms

BEV	Battery Electric Vehicle
BTL	Biomass-to-Liquid
CAI	Controlled Auto Ignition
CI	Compression Ignition
CI-DF	Compression Ignition Dual Fuel
CNG	Compressed Natural Gas
CO2eq	Carbon Dioxide equivalent
CO	Carbon monoxide
DF	Dual Fuel
DME	Di-Methyl Ether
ETBE	Ethyl Tert-Butyl Ether
FAME	Fatty Acid Methyl Ester
FC	Fuel Cell
FT	Fischer-Tropsch
GHG	Greenhouse Gas
GTL	Gas-to-Liquid
HCCI	Homogeneous Compression Charge Ignition
HDV	Heavy Duty Vehicle
HEFA	Hydrotreated Esters and Fatty Acids
HFO	Heavy Fuel Oil
HVO	Hydrotreated Vegetable Oil
LBG	Liquefied BioGas
LDV	Light Duty Vehicle
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MGO	Marine Gas Oil
MTBE	Methyl Tert-Butyl Ether
NEDC	New European Drive Cycle
NG	Natural Gas
NOx	Nitrogen oxides
OEM	Original Equipment Manufacturer
(nv)PM	(non volatile) Particulate Matter
PN	Particulate number
PHEV	Plug-in Hybrid Electric Vehicle
RDE	Real Driving Emissions
RED	Renewable Energy Directive
REx	Range Extender engine
SI	Spark Ignition
SI lean	dedicated spark ignition engine running with excess air
STRIA	Strategic Transport Research and Innovation Agenda
SIP	Synthetic Iso-Paraffinic
SPK	Synthetic Paraffinic Kerosene
TWC	Three-Way Catalyst
TTW	Tank To Wheel
WTT	Well To Tank
WTW	Well To Wheel

7.2 Technical glossary

Technology and fuels	Description	Why is it is being developed?	Benefits
Ethanol and derivatives			
Ethanol	Alcohol fuel, which can be produced from renewable agricultural feedstocks. Can be blended to very high levels into gasoline for use in internal combustion engine vehicles.	Bioethanol is a way to propel vehicles on a renewable, more environmentally-friendly fuel without resorting to alternative drivetrains and changing driver behaviour	Can have lower WTW GHG emissions as long as sustainably sourced, no changes to driver behaviour, high-octane fuel
ETBE	Ethyl Tert Butyl Ether An ether used as a fuel oxygenate, produced via the chemical reaction of ethanol and isobutylene. Most often used as oxygenate to gasoline.	It is used as a sustainable octane enhancer with minimum distillation curve impact	Sustainable octane enhancer. Little impact on other gasoline properties
ED95	An ethanol-based blend of 95% ethanol and 5% ignition improving additives for adapted diesel engines.	A sustainable propulsion fuel for use in engines using the inherently high efficiency diesel cycle	Lower engine out emissions of PM and NOx comparing to diesel
Methanol and derivatives			
MTBE	Methyl Tert Butyl Ether An ether used as a fuel oxygenate, produced via the chemical reaction of ethanol and isobutylene. Most often used as oxygenate to gasoline.	It is used as a (sustainable) octane enhancer with minimum distillation curve impact. It is currently cheaper than ETBE.	Sustainable or cheaper fossil octane enhancer. Little impact on other gasoline properties
DME	Di-Methyl Ether Produced by hydration of methanol for use in CI engines	DME has a similar cetane number and therefore combustion properties than diesel. It can be derived from a variety of sources, either renewable or fossil, which makes it a versatile and possibly low carbon fuel	Similarity to diesel. No carbon to carbon bonds mean no engine out PM emissions
MD95	Similar to ED95 but with methanol	See ED95, if produced sustainably	see ED95
Other Biofuels			
FAME	Fatty Acid Methyl Ester Type of ester derived from transesterification of fats with methanol. Can be blended to high levels into diesel for use in CI combustion engines	FAME, often referred to as biodiesel, is a way to relatively easily and cheaply increase the renewable content of a diesel fuel	Can have lower WTW GHG emissions as long as sustainably sourced

Technology and fuels	Description	Why is it is being developed?	Benefits
FT	Fischer-Tropsch synthesis Liquid biofuels can be produced from syngas, which can be derived from a variety of biomass feedstocks, using FT synthesis	Biofuels are a relatively easily and cheaply increase the renewable content of a diesel fuel	Can have lower WTW GHG emission as long as sustainably sourced, no changes to driver behaviour, higher quality fuel than conventional diesel
HVO	Hydrotreated Vegetable Oil Hydrotreating is an alternative process to esterification to produce diesel from biomass. HVOs are commonly referred to as renewable diesel.	Biofuels are a relatively easily and cheaply increase the renewable content of a diesel fuel	Lower WTW GHG emissions when sustainably sourced
SPK	Synthetic Paraffinic Kerosene or iso-paraffins There are 5 major fuel routes approved for its use in civil aviation: FT-SPK, HEFA-SPK, HFS-SIP, FT-SPKA/A and ATJ-SPK. There are other seven routes currently under approval process, plus other 15 waiting to enter the process. Sustainability of those pathways depends upon the feedstock and way of production.	In the absence of radical re-designs of aviation powertrains, aviation biofuels are considered the primary way to reduce the carbon footprint of the industry	Reduced GHG emissions
Natural gas, propane and derivatives			
CNG	Compressed Natural Gas Methane rich gas stored at high pressure, used as fuel in internal combustion engines	Favourable fuel duty relative to gasoline & diesel. Lower tailpipe CO_2 emissions due to higher H/C ratio.	Can reduce GHG emissions slightly if methane slip can be avoided. No PM emissions. Could be used as interim fuel to biomethane
LNG	Liquefied Natural Gas Methane rich cryogenic fluid used as fuel in internal combustion engines	Can be used in dual-fuel operation with heavy duty diesel engines, such as ships, trains and large trucks.	See CNG. Higher energy density by volume than CNG
LPG	Liquefied Petroleum Gas A mixture of light gaseous hydrocarbons. LPG is stored as a liquid under approx. 5bar pressure predominantly for use in SI engines	Can replace gasoline in internal combustion engines with retro-fit technology	Lower pollutant emissions, relatively small GHG emissions benefits, lower cost to drivers if taxes kept low

Technology and fuels	Description	Why is it is being developed?	Benefits
GTL	Gas To Liquids A process by which natural gas is converted in liquid fuels such as gasoline, diesel or jet fuel. Most commonly done through Fischer-Tropsch (FT) synthesis	GTL liquids can be used as direct replacement for conventional fuels.	Possible way of making use of stranded gas and methane that would otherwise be flared
Electricity			
BEV	Battery Electric Vehicles Vehicles propelled by electric motors using electrical energy stored in on-board batteries	BEVs are an alternative to conventional internal combustion vehicles	No pollutant or CO2 emissions on a Tank-To-Wheels basis, and high efficiency. Low GHG emission and OPEX depend on the electricity source
PHEV	Plug-in Hybrid Electric Vehicles Vehicles with two propulsion systems on-board (electric motor and internal combustion engine) that can work simultaneously or in isolation.	PHEVs are transitional between conventional and electric vehicles or a solution for vehicles with limits to full electrification	Working in electric mode provides the same benefits as EVs, but PHEVs offer flexibility and reduce factors such as range anxiety
Fuel Cells			
Hydrogen Fuel Cell vehicles	Fuel cells produce electric current through a chemical reaction, which propels a vehicle using electric motors. Hydrogen is the most common fuel, stored on board in pressurised tanks. Other FC technology using gasoline, natural gas or alcohol is also being developed, but less commen	Second most common alternative powertrain solution to the conventional internal combustion engine, after EVs. They could have a higher range than EVs as well as allow quicker recharge times depending on on-board storage and refuelling infrastructure. They also have a similar infrastructure model to the conventional oil industry.	Fuel cell vehicles emit no GHGs and pollutants Tank-to-Wheel. Hydrogen as a fuel can be generated in a variety of ways, which include renewable routes.
Diesel			
CI	Compression Ignition Combustion of fuel by high compression of the air inside a cylinder		High efficiency and cost-effective technology
Dual-Fuel	Co-combustion of diesel with another fuel. A small proportion of Diesel (pilot injection) is required to ignite the second fuel	Allows to use other types of fuel in diesel cycle engines	High diesel like efficiency. Same benefits as offered by the alternative fuel used (e.g. LPG, CNG, LNG)

Technology and fuels	Description	Why is it is being developed?	Benefits
HPDI	High Pressure Direct Injection A technology developed by Westport specifically for natural gas, which injects both the alternative fuels and the small amount of diesel as pilot fuel directly into the cyclinder	The technology maximises the use of alternative fuel while maintaining equal horsepower and torque characteristics	Overall benefits the same as with the use of natural gas
HCCI	Homogeneous Charge Compression Ignition A type of internal combustion process in which fuel and air are compressed to the point of auto-ignition	High efficiency at low engine out emission levels	Achieves very low levels of NOx emissions without a catalytic converter
MGO	Marine Gas Oil Oil made from distillate only, roughly equivalent to No. 2 fuel oil	With restrictions put on pollutant emissions for inland maritime, low emission fuels allow to avoid expensive retrofit costs	Much less pollutant emissions than HFO
HFO	Heavy Fuel Oil Pure or nearly pure residual oil, roughly equivalent to No. 6 fuel oil	-	The cheapest fuel for marine applications
Gasoline			
SI	Spark Ignition Internal combustion engine in which combustion process is initiated by a spark plug		
CAI	Controlled Auto Ignition Essentially a HCCI for gasoline, where thermal ignition conditions are achieved at the end of compression	see HCCI	See HCCI
Aftertreatment			
TWC	Three way catalyst An emissions control device through catalysing a redox reaction (oxidation and reduction)	Increasingly stringent pollution limits require manufacturers to research into novel catalytic solutions	Decreased amounts of HC and CO (reduced to carbon dioxide and water)
EGR	Exhaust Gas Recirculation Engine technology that takes some exhaust gas and feeds this back into the engine. This has a dilution effect that lowers the combustion temperature ensuring lower levels of NOx		Decreased amount of NOx pollutant emissions

Technology and fuels	Description	Why is it is being developed?	Benefits
DOC	Diesel Oxidation Catalyst A device utilising a chemical process to break down pollutants into less harmful components		Decreased amount of HC and CO pollutant emissions
SCR	Selective Catalytic Reduction An advanced active emissions control technology that injects urea into the exhaust of the diesel engine.		Breaks down NOx into less harmful N2.
DPF / GPF	Diesel / Gasoline Particulate Filter. A filter that traps particulate matter. When full it needs regeneration through retarding the combustion to generate enough heat to oxidise the PM.		Decreased amount of PM emissions
LNT	Lean NOx Trap Stores the NOx temporarily when in the correct temperature range, but requires regeneration. This requires the engine to run stoichiometric or rich to allow the NOx to be converted to N2		Breaks down NOx into less harmful N2.

7.3 Impact of alternative fuel deployment and development

In this section alternative fuel and powertrain combinations are scored on their potential to meet key EC objectives by 2050 using the following scoring criteria.

Criteria	Definition	Low	Medium	High
TTW GHG emissions	Engine efficiency improvement potential to 2030 relative to the incumbent technology (e.g. 40% now to 45% in 2030 is 5% improvement)	Under 5%	5 to 10%	Above 10%
TTW noxious emissions	Contribution to TTW noxious (specifically NOx & PM) emissions reduction potential to 2030 compared to incumbent technology (incl. after treatment) on a vehicle basis	No material change	Less than an order of magnitude improvement	More than and order of magnitude improvement
EU competitive ness	On balance, contribution to a competitive advantage for the EU industry	Low potential	Medium potential	High potential

This is repeated for each transport mode. The tables have been compiled based on expert knowledge, survey responses, and discussions held at a stakeholder workshop on 24 May 2016 (see list of stakeholders consulted in Annex 7.4).

7.3.1 LDV

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
SI	Alcohols, ethers & esters	Slight efficiency improvements of up to 5% through higher RON. Fuels to include are ethanol, methanol and other alcohol mixtures, but also MTBE and ETBE This could allow further downsizing / speeding / enleanment	High Alcohol blends significantly reduce engine out PM and NOx. Note: the emission of non-regulated aldehyde emission could increase	Optimised engine and fuel technology would increase EU automotive industry competitiveness
CI	Alcohols, ethers & esters	Engine efficiency similar to current CI diesel engines	Significant improvement demonstrated from DME and ED95. FAME less so	Optimised engine and fuel technology would increase EU automotive industry competitiveness
FC	Alcohols, ethers & esters	FC has typically a higher engine efficiency especially at part load (real world) conditions	Very low emissions from FC systems	Optimised engine and fuel technology would increase EU automotive industry competitiveness
CI	gasoline/naphtha	For use of naphtha rather than diesel	Specifically particulates reduction	
SI	Liquid petroleum gas (LPG) & bioLPG	Improvement from compression ratio increase and direct injection	Three way catalyst already very effective Reduction in PM	LPG in direct injection engines fits well in European engine designs and bioLPG production fits with HVO production
CI	Natural gas / bio-methane	Efficiency improvement relative to the CI diesel engine is difficult A dual fuel system using a CI combustion process would need to utilised here	DF systems should significantly reduce PM. Engine out NOx might be reduced by finding a better trade-off with CO2. Aftertreatment systems could be optimised further	European countries have developed very up to date technologies for natural gas vehicles, for which Europe still has a leading role.

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
SI	Natural gas / bio-methane	Higher efficiency of SI engines through the use of gas is possible in the form of downsizing or enleanment New technologies such as HPDI, high pressure direct injection, downsizing with turbo-charging, etc. can lead to higher energy efficiency, and sharp decrease of CO2 emissions: even to 40% compared to the present gasoline engines is possible in prospect.	Natural gas engines emit extremely low PM, and low regulated pollutants, even without the complex treatment systems used with other fuels. Very low or absent are also other non-regulated noxious substances, in particular unburned carcinogenic substances such as aromatics.	European countries have developed very up to date technologies for natural gas vehicles, for which Europe still has a leading role.
CI	SPFs	additional tuning possible Difficult to improve CI engine efficiency	Potentially very beneficial for existing fleet CI engine aftertreatment very effective already	Opportunity for EU to develop new innovative fuel technology
SI	SPFs	depends on final product quality (eg RON)	Depends on final quality (eg aromatics content)	Opportunity for EU to develop new fuel innovative technology

7.3.2 HDV

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
CI	Alcohols, ethers & esters	Engine efficiency similar to current CI diesel engines	Significant improvement demonstrated from DME and ED95. FAME less so	Optimised engine and fuel technology would increase EU automotive industry competitiveness
SI	Liquid petroleum gas (LPG) & bioLPG	Improvement from compression ratio increase and direct injection	Three way catalyst already very effective Reduction in PM	LPG in direct injection engines fits well in European engine designs and bioLPG production fits with HVO production

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
CI	Natural gas / bio-methane	Efficiency improvement relative to the CI diesel engine is difficult. Lower PM & NOx would allow for improved fuel eff.	DF systems do significantly reduce PM. Engine out NOx might therefore be reduced and aftertreatment systems optimised	European countries have developed very up to date technologies for natural gas vehicles, for which Europe still has a leading role.
SI	Natural gas / bio-methane	New technologies such as HPDI, high pressure direct injection, etc. can lead to higher energy efficiency, and sharp decrease of CO2 emissions, thus increasing the CO2 saving compared to HD diesel engines.	Natural gas engines emit extremely low PM, and low regulated pollutants, even without the complex treatment systems used with other fuels. Very low or absent are also other non-regulated noxious substances, in particular unburned carcinogenic substances such as aromatics. Euro VI SI & CI engines already have very low TTW noxious emissions	European countries have developed very up to date technologies for natural gas vehicles, for which Europe still has a leading role.
CI	SPFs	Difficult to improve CI engine efficiency	SCR+DPF aftertreatment very effective	Europe leading fuel production technology
Turbine	SPFs	turbo-engines are not efficient in small scale		patent priority and proprietary technology
Other	SPFs	composite piston-turbo cycle allows for very high pressure ratios	lean operation	patent priority and proprietary technology

7.3.3 Rail

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
CI	Biodiesel	For B20, engine efficiency similar to current fuel. For higher ratio, the performances of existing locomotive deiesel engine can been affected.	No change	Developing new engine able to run with more than 20% biodiesel could increase EU competitiveness

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
SI	LNG	Energy efficiency is in the same range as the diesel engine.	NOx and PM emissions are by 70% lower.	Developing new locomotive offers alternative decarbonisation pathway for the transport sector.

7.3.4 Waterborne transport

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
CI	Biodiesel	Pressurizing the cylinder helps to reduce the emissions (NOx) and optimise the combustion process. Electronic control injection will improve the degree of fuel atomisation.	No Significant change	Optimised engine technology and fuel handling techniques would increase EU competitiveness
CI, DF	Methanol	Methanol has high octane number - very efficient engine performance. Tests run by different engine designers indicated that the fuel efficiency is the same or better when running on methanol. Advanced injection systems potentially provide further improvements in terms of efficiency	Global reduction of noxious emissions proved by Motorways of the Seas project. NOx emissions during combustion are reduced by approximately 60 % when running on methanol compared to HFO. Significant reduction in SOx Advanced injection systems potentially provide further improvements in terms of pollutant emissions	World's first methanol powered ferry was launched through an EU project.

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
SI	Natural gas / bio-methane	SI lean burn gas engine has high energy efficiency only at high loads. For the entire load range, energy efficiency can be in the same range as the diesel engine, but the emissions (NOx) are kept low. It Is sensitive to gas quality and not suitable for retrofit existing engine.	Using LNG gaseous emissions meet IMO Tier III. SOx emission is eliminated. PM is close to zero. NOx is reduced by 80-90% due to low flame temperatures during lean burning. SI marine engines emit ultrafine PM.	European manufacturers are world leaders in developing robust engines for LNG-fuelled ships. Bio-methane can be produce locally, offering the perspective of reducing EU energetic dependency.
CI, DF	Natural gas / bio-methane	DF has diffusion burning which ensure better capability of burning gases. MAN states that its dual-fuel LNG engine achieves 50 % peak thermal efficiency, compared to diesel engines, with lower fuel consumption. Conversion of existing engines with rebuilding work. Sensitive to gas quality. Advanced injection systems potentially provide further improvements in terms of efficiency	DF systems have very good influence on PM reduction. Aftertreatment (EGR, SCR) of exhaust gases is needed to comply with IMO Tier III-NOx emission limits. Advanced injection systems potentially provide further improvements in terms of pollutant emissions	European manufacturers are world leaders in developing robust engines for LNG-fuelled ships. Bio-methane can be produce locally, offering the perspective of reducing EU energetic dependency.

7.3.5 Aviation

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
Turbofan	SPK (FT,HEFA)	SPK is less energy dense than conventional jet, but it has higher specific energy Small gain.	Lower nvPM as much as related with a relatively lower aromatics and S content.	As there are CO2 global reduction targets for aviation, having available and affordable ways for aviation will be key for sector competitiveness

Powertrain technology	Fuel	TTW GHG emissions	TTW noxious emissions	EU competitiveness
Turbofan	SIP	Higher energy content per volume, lower per weight. Small gain.	Lower nvPM as much as related with a relatively lower aromatics and S content	As there are CO2 global reduction targets for aviation, having available and affordable ways for aviation will be key for sector competitiveness
Turbofan	ATJ	Higher energy content per volume, lower per weight. Small gain.	Lower nvPM as much as related with a relatively lower aromatics and S content	As there are CO2 global reduction targets for aviation, having available and affordable ways for aviation will be key for sector competitiveness
Turbofan	HEFA+	Higher energy content per volume, lower per weight. Small gain.	Lower nvPM as much as related with a relatively lower aromatics content.	No significant technology change, but decarbonisation is a key for competitiveness in aviation.
Turbine	LNG		Lower PM and NOx	

7.4 Stakeholders consulted

- ACI
- Airbus
- Bauhaus
- Becker Marine Systems
- Biochemtex
- British Airways
- CLEPA
- CONCAWE
- Daimler
- DNV/GL
- ENI
- ERTRAC
- FIAT
- Honeywell
- ICCT
- IDIADA
- Italian Ministry of Transport (CPT/IMO)
- JRC
- Lufthansa
- MIT
- Renault
- Repsol
- Rolls-Royce
- SAFRAN
- Scania
- SENASA (Services and Studies for air navigation and aeronautical safety)
- T&E
- Toyota Europe
- UIC
- Volkswagen