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Research and innovation in low emission alternative energy for transport

An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)

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Contents

Abstract

This report provides a comprehensive analysis of research and innovation in alternative fuels in selected European Union (EU) funded projects from 2007 onwards. It identifies relevant researched technologies by fuel type and their phase of development. The results show that liquefied petroleum gas technologies are fully developed while methane-based fuels are in the last phases of development. However, they have a limited overall environmental advantage over conventional fuels, since they are equally mostly based on fossil energy sources and might have issues related to pollutant emissions and leakage. Technologies for synthetic paraffinic fuels, and alcohols, esters and ethers are in earlier phases of development hinting to a steady shift to a more sustainable production. So far, road transport has the highest use of alternative fuels in the transport sector. Despite financial support from the EU, advances have yet to materialise suggesting EU transport decarbonisation policies should not expect a radical or sudden change, and therefore, transition periods are critical.

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Executive summary

The Transport Research and Innovation Monitoring and Information System (TRIMIS) is the analytical support tool for the establishment and implementation of the Strategic Transport Research and Innovation Agenda (STRIA), and is the European Commission's (EC) instrument for mapping transport technology trends and research and innovation capacities.

Seven STRIA roadmaps have been developed covering various thematic areas, namely:

- Cooperative, connected and automated transport;
- Transport electrification;
- Vehicle design and manufacturing;
- Low-emission alternative energy for transport;
- Network and traffic management systems;
- Smart mobility and services; and
- Infrastructure.

Policy context

In May 2017, the EC adopted STRIA as part of the 'Europe on the Move' package, which highlights main transport research and innovation (R&I) areas and priorities for clean, connected and competitive mobility to complement the 2015 Strategic Energy Technology Plan.

One of the main tasks of TRIMIS is to assess the development and implementation of new technologies in Europe for each roadmap. This report provides such an assessment for the Low-emission alternative energy for transport STRIA roadmap. In order to do so, TRIMIS has used recent European Framework programmes.

Key conclusions

The findings support two crucial policy lessons for the future. First, new technologies and changes in the Alternative Fuels (AF) market need some time to materialise. It means policies should not expect a radical or sudden change, and therefore, transition periods are critical. Second, different fuel types have different development phases. Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG) fuels and related technologies are already available on the market. However, they have a limited overall environmental advantage over conventional fuels, since they are equally mostly based on fossil energy sources and might have issues related to pollutant emissions and leakage, which make the overall environmental benefit of such fuels questionable. First-generation of Synthetic Paraffinic Fuels (SPF) and alcohols, esters and ethers are already available across Europe, but these have questionable sustainability aspects in terms of the land-use competition with food crops. Current research focuses on more sustainable generation of SPF and alcohols, esters and ethers, which will require more extended periods to be on the market. Moreover, they have environmental advantages over CNG, LNG and LPG and therefore focusing future research on advanced biofuels should be included into any future policy development around biofuels. From a policy point of view, CNG, LNG and LPG offer possible short – and medium-term solutions if the associated emission and leakage issues are overcome, however the electrification of transport might be a more beneficial and attractive solution to long-term decarbonisation. Improved and more sustainable version of SPF and alcohols, esters and ethers might also provide a long-term solution. Nevertheless, all policies should ensure clean and decarbonised transport and consider broader social, environmental and economic impacts.

Main findings

Some main findings arise from this report:

- Methane based fuels (e.g. CNG, LNG) receive the greatest attention in terms of the number of projects (90) and funding (504 M€). These fuels are in their last development phases with TRLs close to 9. Research in this area is not on the fuel itself but on how to store and handle it, addressing in this way issues related to methane leakage.
- LPG technologies are fully developed. However, they have a limited overall environmental advantage over conventional fuels, since they are equally mostly based on fossil energy sources. There are few research projects (38) and the absence of linked technologies. The low level of R&I might also be explained by the

potential electrification of the transport system which would make this AF outdated. Current research focuses on improving car conversion kits and Bio-LPG.

- SPF also benefit from European funding with 498 M€ and 84 projects. The majority of the projects link to the first development phases with TRLs up to 4. In other words, SPF research focuses on biomass production using more sustainable types of biomass. The industry therefore sees further improvements with more sustainable production like FT, which currently has very little or no impact on the market.
- Alcohols, esters and ethers come in third place of number of projects (77 projects) and funding received (429 M€). Research in this area focuses on biomass production and understanding the blend limits (the so-called blend wall).
- There are not many technologies in the AF roadmap, particularly when compared to other roadmaps. For instance, in this analysis the researchers only identified the top 15 technologies, whereas for other roadmaps there are at least top 20 technologies.
- There are no expectations of relevant or radical changes in the near future. Moreover, registration of electric vehicles (EV) and hybrid electric vehicles (HEV) is growing faster than other alternatively-fuelled vehicles and account together for 60 % of the new registered AF vehicles, with gas vehicles in decline since less than 10 % of new AF cars rely on NG, suggesting users see electricity as a more attractive option. Therefore, changes in the AF market need some time to materialise.
- Bigger MSs tend to invest more and have more projects than smaller MSs, but in normalised terms (e.g. investment per capita); the five most important players are Sweden, Austria, Finland, Belgium and Germany.
- Road transport receives more alternative fuel-related funding than any other transport mode whilst the number of rail projects on alternative fuels on TRIMIS database is rather small. This lies in the electrification of the railway tracks, since all the important ones in Europe are already electrified and in general, only minor lines use diesel. The main advancement in this transport mode might be a shift to electrification or hydrogen rather than run on diesel, always studying its economic feasibility first.

Related and future JRC work

TRIMIS is consolidating and expanding the data repository to better assess R&I efforts of projects not funded by the EU or MS. As part of this effort, information on technologies, patents and publications, and various other topics of interest, including on transport infrastructure will be included in the future. TRIMIS will continue to provide support to STRIA and, based on its research, provide recommendations to policymakers. The present report is part of the continuous support to the implementation of STRIA. The new version of AF roadmap will include hydrogen. TRIMIS will consider it when updating this report.

Quick guide

The report is structured as follows: Chapter 1 gives a brief introduction and sets the scope of the document. Chapter 2 provides the methodological approach followed in this report. Chapter 3 provides the market context for the AF roadmap. Chapter 4 sets the policy context for AF. Chapter 5 offers results on key research and innovation (R&I) dimensions such as framework programmes, national funding, geographical and organisational distribution of funds, projects per MS, mode of transport and type of fuels. It includes an analysis of the technology development phases and the top 15 AF technologies in Europe in terms of R&I investments. Chapter 6 shows R&) assessment of the most relevant European projects. Chapter 7 provides a set of key performance indicators (KPIs) for monitoring the implementation of the AF roadmap. Finally, Chapter 8 concludes with recommendations and policy lessons.

1 Introduction

In May 2017, the European Commission (EC) adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the 'Europe on the Move' package (European Commission, 2017a; 2017b), which highlights main transport research and innovation (R&I) areas and priorities for clean, connected and competitive mobility to complement the 2015 Strategic Energy Technology Plan (European Commission, 2015).

The STRIA roadmaps set out common priorities to support and speed up the research, innovation and deployment process leading to radical technology changes in transport. Seven STRIA roadmaps have been developed covering various thematic areas, namely:

- Cooperative, connected and automated transport;
- Transport electrification;
- Vehicle design and manufacturing;
- Low-emission alternative energy for transport;
- Network and traffic management systems;
- Smart mobility and services; and
- Infrastructure.

The STRIA Roadmap for Low-emission Alternative Energy for Transport (AF roadmap hereinafter) focuses on renewable fuels production, alternative fuel infrastructure as well as the impact on transport systems and services of these technologies for road, rail, waterborne transport and aviation. The current version of the AF roadmap, first published in 2016, is currently under revision with plans to include Hydrogen in the list of Alternative Fuels. The Directive 2014/94 on the deployment of alternative fuels (AF) infrastructure defines AF as "*fuels or power sources which serve, at least partly, as a substitute for fossil oil sources in the energy supply to transport and which have the potential to contribute to its decarbonisation and enhance the environmental performance of the transport sector*." Four AFs fall under this roadmap:

- Methane-based fuels (e.g. Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), Bio-methane and E–gas). All transport modes can use it, with the exception of aviation.
- Propane and butane based fuels (e.g. Liquefied Petroleum Gas (LPG) and BioLPG), used only in road transport.
- Alcohols, Ethers and Esters (e.g. Ethanol, Butanol, Methanol, Ethanol-based blend of 95 % (ED95)). All transport modes can use it, with the exception of aviation.
- Synthetic paraffinic and aromatic fuel (e.g. Hydrotreated Vegetable Oil (HVO) and Gas to Liquid (GTL)). All transport modes can use it, including aviation.

Hydrogen and electricity are also part of the Directive 2014/94 on the deployment of alternative fuels, but they come under the STRIA Roadmap of Transport Electrification. Hydrogen will be included in the revised version of the AF roadmap, due by the end of 2019. Nonetheless, this report does not include Hydrogen projects and technologies. There are four main challenges related to AFs: methane leakage; fuel storage, handling and injection systems; better understanding of blend limits; and production of process scale, cost-effectiveness and lack of infrastructure. A common objective for all the fuels is to reduce pollutant emissions.

The EC's Joint Research Centre (JRC) has developed the Transport Research and Information Monitoring and Information System (TRIMIS) ([1]) to support the implementation of STRIA. TRIMIS provides a holistic assessment of technology trends, transport R&I capacities and publishes information and data on transport R&I (Tsakalidis et al. 2018). Funded under the Horizon 2020 Work Programme 2016-2017 on smart, green and integrated transport, TRIMIS enables understanding of R&I needs and provides evidence-based recommendations to policymakers. The present report is part of the continuous support to the implementation of STRIA. A new version of the AF roadmap is being developed in 2019. TRIMIS researchers have attended two workshops held in DG Move premises to discuss the updated version of the roadmap. In the first workshop they explained what TRIMIS is and how it can help the development of the new roadmap. They received some feedback which was considered for this report. In the second workshop they shared the main results of this report. This new version of the AF roadmap will include hydrogen. TRIMIS will consider it when updating this report.

(1) https://trimis.ec.europa.eu/

This report is divided into eight sections. After this brief introduction, Section 2 outlines the methodological approach followed in this review. Section 3 presents the market context for AF. Section 4 sets the policy context for AFs. Section 5 provides an analysis of Horizon 2020 (H2020) and Framework Programme 7 (FP7) research framework programme funding calls and how these are distributed across fuels, countries and transport modes. Section 6 presents an R&I assessment of the most relevant European projects. Section 7 provides a set of key performance indicators (KPIs) for monitoring the implementation of this roadmap. Finally, Section 8 outlines recommendations and policy lessons for the future.

2 Methodological approach

The main goal of the study is to review European Union (EU) AF research funded projects from recent EC research framework programmes (FP). In order to do so, we developed a methodological approach consisting of three steps, namely:

1. The consolidation and further development of the TRIMIS project and programme database.
2. The development of a methodology for the project assessment.
3. The development of a methodology for the identification and assessment of the technologies researched within FP.

A brief description of these steps is provided below.

2.1 Database development and labelling

TRIMIS hosts an extensive database of EU and Member State (MS) programmes and projects (currently over 7000) on transport R&I and is continuously updated. Projects funded by the European FPs are retrieved through an automated data interchange, while projects funded by MS are inserted manually by national contact points. This study focuses on EU-funded projects in the last two FP research programmes. While recent projects provide an indication of the state of R&I, MS projects are less reliable.

A key step is to identify those projects that fall under the AF roadmap. The original STRIA roadmap defines the scope of AF. Projects are evaluated, categorised and then published (van Balen et al., 2019). A TRIMIS transport specialist, with a deep understanding of all STRIA roadmaps, manually categorised the projects. Many projects cover energy for transport, therefore only projects that mentioned a considerable AF research component in the project description fall under the AF roadmap. The specialists also assessed the projects against several other variables, including transport mode and geo-spatial scope.

2.2 Identification and assessment of the technologies researched within FP

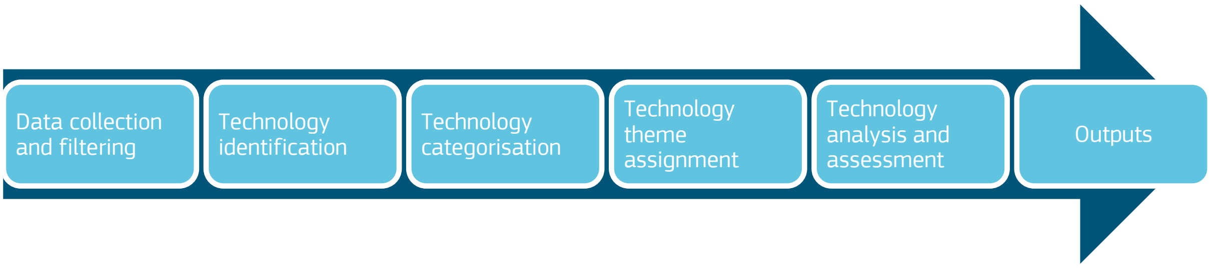
A TRIMIS sub-task is to create an inventory and report on new and emerging transport technologies and trends (NETT) in transport (Gkoumas et al. 2018). The aim is to assist policymakers and researchers to identify opportunities for transport innovation and adopt supportive measures. The TRIMIS NETTs analysis focuses on FP7 and H2020 projects that undertake research on transport technologies. Out of 2 242 projects, 797 technologies were identified within 45 technology themes. These figures are based on a general assessment of TRIMIS projects. An iterative approach resulted in a consistent taxonomy for transport technologies and technology themes, which was applied to the AF roadmap.

A number of overarching technology themes were defined when the technology list was established. Themes enable a better understanding of technologies clusters and research. An extensive list of themes was created. This was then reduced to 45 themes under which all technologies could be placed.

Projects were then assessed on the extent to which they focused on AFs. If they did, the technologies and themes were highlighted. The funds associated with each technology were determined by linking them with the total project budget. If the project undertook research on multiple technologies, the budget allocated to the technology was determined by dividing the project budget by the number of associated technologies. This approach has limitations but is considered transparent and appropriate in the absence of technology-budget reports.

In a final step, a set of metrics was established to assess the potential of the technologies to be applied in practice. Figure 1 provides an overview of the methodological steps undertaken.

Figure 1. Technology assessment methodological steps



Source: TRIMIS.

2.3 Project assessment

The TRIMIS database was used to identify current EU programmes funding research on alternative fuels. All related projects within the last two framework programmes (FP7 and H2020) were included in the analysis (see Annex 1). Two new retagging exercises were conducted that consisted of reading all available information (i.e. description of the project, methodology and results). Each project was linked to the fuel (i.e. CNG or LNG, LPG, alcohols ethers esters, and SPF) and the challenge (i.e. methane leakage; fuel storage, handling and injection systems; better understanding of blend limits; production of process scale, cost-effectiveness and lack of infrastructure) being addressed. Although not in the AF roadmap, other challenges such as stakeholder engagement were also included. By adopting this clustering, it is possible to assess R&I findings focusing on specific areas of interest.

3 Market context

According to the European Environmental Agency (EEA), there has been an increase in transport energy consumption in total and relative terms. In 2017, the transport sector accounted for approximately 30.8 % of the final European energy consumption, which is an increase of 2.2 % compared to 2000 (28.6 %) ([2]).Road transport accounted for 71.7 % of total CO_2 emissions, aviation 14 % and waterborne transport 13.4 %. In terms of transport's final energy consumption by origin, 7.4 % (2017) was renewable energy compared to 1.4 % (2004) (Eurostat, 2019). Transport greenhouse gas (GHG) emissions are growing and account for a quarter of the EU's total GHG emissions ([3]) despite improvements in the energy efficiency of vehicles. Increases in transport GHG is due to a demand for both passenger and freight transport resulting from a higher level of economic activity.

In 2012, AF road vehicles represented 3 % of the European fleet, although this includes electric and hydrogen-fuelled vehicles while the use of AF in heavy-duty vehicles (HDV) and in aviation were negligible ([4]). According to the European Alternative Fuels observatory (EAFO) the total fleet of light AF vehicles accounted in 2019 for 10 227 642 vehicles. 77 % of them rely on LPG, CNG cars account for 11.6 % of the vehicles, with 5.7 % of electric vehicles (EV) and the remaining 5.7 % relying on hybrid electric vehicles (HEV). Almost 38 % of new AF registered vehicles in 2019 are EV, LPG follows with 29.3 % of new registered vehicles, HEV account for 22.2 % of new vehicles and the remaining 9.6 % relying on CNG cars. European Automobile Manufacturers Association (ACEA) data indicate similar figures, with only 1.4 % of cars first registered in Europe in the first quarter of 2019 being alternatively-fuelled vehicles other than electric powered vehicles ([5]).This slight change compared to a similar period in 2018 could be due to the unattractiveness of AF, particularly CNG vehicles, to consumers and businesses, and the absence of clear market signals. The statistics for light-duty vehicles (LDV) remain quite low, with only 323 060 of the registered vehicles in 2019 across Europe using alternative fuels, including electricity. 44.8 % of them rely on CNG, with EV and LPG sharing the remaining 28.4 % and 26.8 % of the fleet respectively. The figure for heavy-duty vehicles is quite similar, with only 22 165 of the vehicles not using petrol or diesel. In this case, the use of electricity is negligible and CNG has the lion´s share with 86.4 % of the HDV fleet.

In the case of bioethanol, although E5 fuel (5 % bio-ethanol, 95 % gasoline) is available across the EU, E10 fuel (10 % bio-ethanol) is only available in Belgium, Finland, France and Germany ([6]), despite the majority of post-2002 (spark ignition) vehicles being able to use it without modification. For flexi-fuel vehicles, E85 fuel (85 % bio-ethanol) is available in four Member States (France, Germany, Netherlands and Sweden), although other sources indicate that it is sporadically available in Austria, Hungary and Spain ([7]).

In 2016, the EU consumption of biogasoline was 2.6 million tonnes of oil equivalent (Mtoe) or 3.3 % by energy content of total gasoline consumption ([8]). Consumption of biodiesel fatty acid methyl esters (FAME) and hydrogenated vegetable oil (HVO) was 11.1 Mtoe (5.1 % by energy content of total diesel consumption), meaning that biofuels accounted for 4.6 % (by energy content) of transport gasoline and diesel consumption. The US Global Agricultural Information Network (GAIN) predicts that by 2018 these European figures would rise to 5.2 %, with 3.6 % blending (by energy content) of bio-ethanol in gasoline and 5.8 % (by energy content) for bio-diesel ([9]). These are equivalent to blending rates on a volume basis of 5.7 % for bioethanol and 7.2 % for biodiesel.

Fuels Europe (2018) suggests that the consumption of liquefied petroleum gas (LPG) rose from 26.1 million tonnes (2005) to 30.9 million tonnes (2017), an increase of 18.4 % (or approximately 1.4 % per annum) ([10]).

(2) https://op.europa.eu/en/publication-detail/-/publication/f0f3e1b7-ee2b-11e9-a32c-01aa75ed71a1

(3) https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-11

(4) https://ec.europa.eu/transport/sites/transport/files/themes/urban/studies/doc/2015-07-alter-fuels-transport-syst-in-eu.pdf

(5) https://www.acea.be/press-releases/article/fuel-types-of-new-cars-diesel-17.9-petrol-3.3-electric-40.0-in-first-quarte

(6) https://www.acea.be/publications/article/e10-petrol-fuel-vehicle-compatibility-list

(7) https://www.epure.org/about-ethanol/fuel-market/fuel-blends/

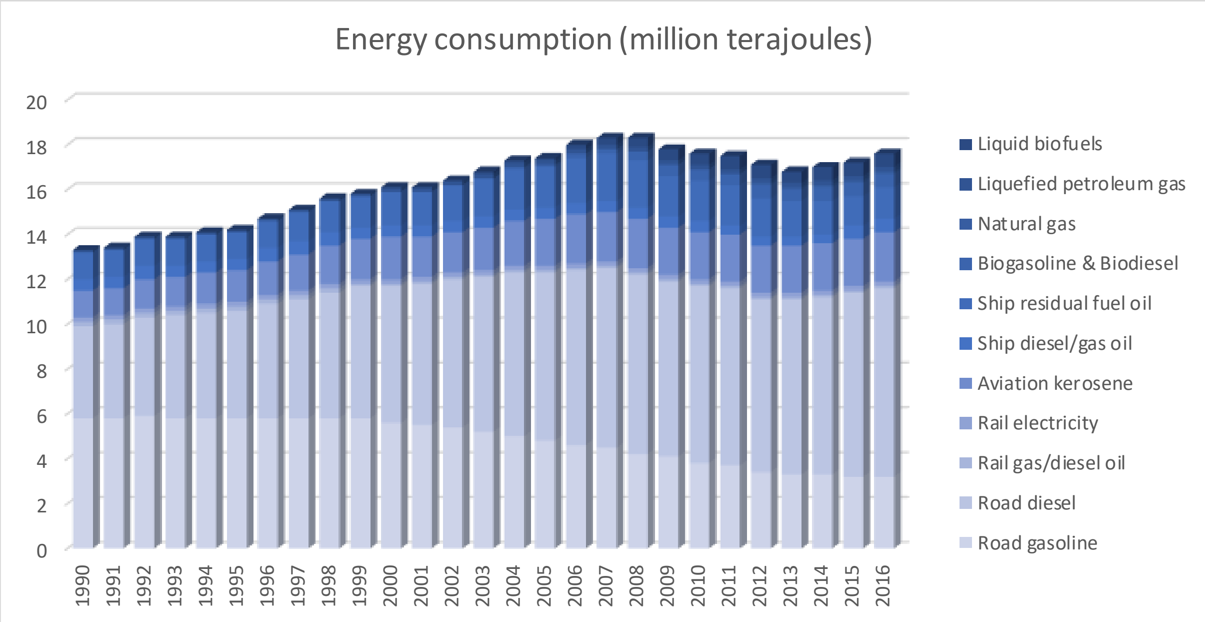
(8) https://bioenergyinternational.com/biofuels-oils/eu-biofuel-consumption-2016-increased-marginally-14-4-mtoe

(9) https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_7-3-2018.pdf

(10) https://www.fuelseurope.eu/wp-content/uploads/FuelsEurope-Statistical-Report-2018.pdf

To date, a number of airlines ([11,12,13,14]) have flown trial flights using blends of up to 50 % biofuels (the maximum allowed under current certification regulations). However, the widespread adoption of biofuels by the aviation industry is not expected before 2030 ([15]). Figure 2 presents energy consumption by transport mode and type of fuel. As previously stated, the last few years has seen the slow evolution of renewable transport fuels.

Figure 2. Energy consumption by transport mode and type of fuel



Source: EEA

(11) https://www.lufthansagroup.com/en/responsibility/climate-environment/fuel-consumption-and-emissions/alternative-fuels.html
(12) https://www.businessgreen.com/bg/news/3063810/ready-for-take-off-virgin-completes-commercial-flight-using-waste-based-biofuel
(13) https://www.virgin.com/richard-branson/low-carbon-fuel-breakthrough-virgin-atlantic
(14)https://www.reuters.com/article/airlines-biofuels-klm/klm-trials-biofuel-powered-flights-between-amsterdam-and-oslo-idUSL5N1734WP
(15) https://www.iea.org/newsroom/news/2019/march/are-aviation-biofuels-ready-for-take-off.html

4 Policy context

This section outlines the policy context in Europe and worldwide that can foster the development of AF. It reviews European transport policy related to low-carbon AF, highlights different European research programmes and summarises key international AF policies.

4.1 Low-carbon alternative fuels in European transport policy

In 2011, the EC published its White Paper on Transport, 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system'. This outlined the Commission's vision for the future of the European transport system and the policies that would be needed to achieve it.

The first two (of ten) goals presented in the white paper relate to alternative fuels:

1. Halve the use of 'conventionally-fuelled' cars in urban transport by 2030; phase them out in cities by 2050; achieve essentially CO_2-free city logistics in major urban centres by 2030;
2. Low-carbon sustainable fuels in aviation to reach 40 % and reduce EU CO_2 emissions from maritime bunker fuels by 40 % (if feasible 50 %) by 2050.

The roadmap recognised the importance of research on sustainable alternative fuels and the need for appropriate infrastructure.

The 2014 alternative fuels infrastructure directive (2014/94) requires MS to develop national policy frameworks for the market development of alternative fuels and their infrastructure. Specific requirements include the availability of CNG refuelling points in urban/suburban and other densely populated areas by 2020 and along the Trans-European Transport Network (TEN-T) core network by 2025. It also requires LNG refuelling points for HDVs, and in maritime ports of the TEN-T core network by 2025 and in inland ports by 2030. The updated Clean Vehicles Directive (Directive (EU) 2019/1161) aims to promote clean mobility solutions in public procurement tenders (purchase, lease, rent or hire-purchase of road transport vehicles, and public service contracts on public passenger transport by road and rail) and thereby raise the demand for and the further deployment of clean vehicles. For light-duty vehicles, the proposal provides a definition of clean vehicles based on a combined CO2 and air pollutant emissions thresholds, while it uses a definition based on alternative fuels (electricity, hydrogen, natural gas including biomethane) for heavy-duty vehicles. It also makes it possible to adopt a delegated act to use emission thresholds for heavy-duty vehicles after a future adoption of CO2 emission standards for such vehicles. CO2 Emission thresholds for light-duty vehicles range between 25 and 40 grams CO2/km for 2025 and drops to zero in 2030. Emissions of air pollutants must be at least 20 % below the emission limits set in Annex I of Regulation (EC) 715/2007 or its successors. The proposal sets minimum procurement targets for each category of vehicle and each Member State. For light-duty vehicles, Member States must reach a share between 16 % and 35 %. For buses, Member States' targets range from 29 % to 50 % (2025) and from 43 % to 75 % (2030), and for trucks from 6 % to 10 % (2025) and from 7 % to 15 % (2030). The proposal introduces a reporting and monitoring framework and abolishes the methodology for monetisation of external effects.

The directive also requires the EU to develop international standard specifications for LNG refuelling points for maritime and inland waterway vessels and for LNG and CNG motor vehicles. The Commission Delegated Regulation (EU) 2019/1745 of 13 August 2019 supplements and amends Directive 2014/94/EU of the European Parliament and of the Council as regards recharging points for L-category motor vehicles, shore-side electricity supply for inland waterway vessels, hydrogen supply for road transport and natural gas supply for road and waterborne transport and repealis Commission Delegated Regulation (EU) 2018/674.

The alternative fuels infrastructure directive is based on the 2009 renewable energy directive (RED) (2009/28). This requires the EU to meet a target of 20 % of total energy needs from renewable sources by 2020. The directive also required 10 % of transport fuels (on an energy basis) to be derived from renewable sources by 2020. Only Finland and Sweden have achieved the 10 % share in renewable energy consumption in the transport sector, with Austria and France close to achieving this target. The original RED was succeeded by an updated directive in 2018 (2018/2001), which extended the overall target to 32 % of total energy needs being met by renewable sources by 2030, with a target for transport of 14 %. The directive also defines criteria to determine the sustainability of biofuels to ensure they are sustainable and environmentally friendly. In addition, the directive imposes a cap on biofuels produced from crops and includes a specific sub-target to encourage the use of lignocellulosic feedstocks such as pellets, and waste.

The 2009 fuel quality directive (2009/30) limits the blending of FAME and ethanol in regular diesel and gasoline to 7 % and 10 % volume respectively. The directive requires fuel suppliers to contribute to reducing transport

GHG emissions by at least 6 % by 2020, compared to the 2010 by using biofuels, alternative fuels and reducing flaring and venting at production sites.

The European strategy for low-emission mobility (16) identified the need to increase the use of low-emission alternative energy for transport. The EC is examining the potential of incentives to innovate for a long-term decarbonisation of transport. It also highlighted the limited role of food-based biofuels, which should not receive public support after 2020, and the importance of developing infrastructure to support the rollout of alternative fuels (including electricity). The strategy acknowledged fuel type options are greatest for passenger cars and buses, and that the solution for rail is electrification. Natural gas has the potential to reduce emissions from shipping and lorries and coaches, with biomethane and synthetic methane providing further decarbonisation in the future. In the medium-term, advanced biofuels would be important for aviation.

Since 2012, aviation fuel consumption and consequent GHG emissions been subject to the EU emissions trading system (ETS). However, the scope was reduced to intra-EEA (European Economic Area) flights by the 2013 'stop the clock' or postponed deadline derogation which remains in place to this day. The regulations for the inclusion of aviation in the EU ETS allows biomass to have zero emissions. This exempts sustainable biofuels from having to surrender allowances. However, there are challenges in tracking the sustainability of the biofuel elements of the fuel uplifted to the aircraft (where fuels with a biofuel content are available) (17) and hence defining the levels of exemption that can be claimed by individual operators.

From 2021, the International Civil Aviation Organisation's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is due to be applied to all international flights between participating countries. The scheme is expected to include an exemption (from the need to purchase offsets for emissions) for sustainable biofuels, although the precise rules for determining the sustainability of biofuels are yet to be published. The EU has not decided how the EU ETS will interact with CORSIA (all 28 EU Member States have committed to joining CORSIA). However, it is likely that airlines will need to comply with the requirements for one of the schemes for all flights and consequently there will be additional incentives for airlines to use sustainable biofuels in the future.

In 2018, the International Maritime Organisation (IMO) adopted a strategy to GHG emissions from ships (18) including energy efficiency regulations (19) which are included Chapter 4 of Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL). These regulations include provision for rating different fuels by their CO_2 emissions per unit of mass, including lower values for alternative fuels such as LPG, LNG, methanol and ethanol (see Table 1).

Table 1. Fuel carbon factors in IMO ship energy efficiency regulations.

Type of fuel	Reference	Carbon content	$t\text{-}CO_2/t\text{-}Fuel$
Diesel/Gas Oil	ISO 8217 Grades DMX through DMB	0.8744	3.206
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.8594	3.151
Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.8493	3.114
Liquified Petroleum Gas (LPG)	Propane	0.8182	3.000
	Butane	0.8264	3.030
Liquified Natural Gas (LNG)	N.A.	0.7500	2.750
Methanol	N.A.	0.3750	1.375

(16) https://eur-lex.europa.eu/resource.html?uri=cellar:e44d3c21-531e-11e6-89bd-01aa75ed71a1.0002.02/DOC_1&format=PDF
(17) The maximum percentage of biofuel in a blend with kerosene is limited by the terms of the ASTM certification for each type of biofuel. The highest blend limit currently allowed is 50 %.
(18) http://www.imo.org/en/MediaCentre/HotTopics/GHG/Pages/default.aspx
(19)http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/M2%20EE%20regulations%20and%20guidelines%20final.pdf

Type of fuel	Reference	Carbon content	$t\text{-}CO_2/t\text{-}Fuel$
Ethanol	N.A.	0.5217	1.913

Source: 'Module 2 – Ship Energy Efficiency Regulations and Related Guidelines' (http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/M2%20EE%20regulations%20and%20guidelines%20final.pdf)

4.2 Low-carbon alternative fuels in European research programmes

Since the FP7 programme, projects related to the low-carbon alternative energy roadmap have been included in EU funding programmes. Research programmes that have funded low-carbon alternative energy (excluding Hydrogen) have been identified using the TRIMIS database. Table 2 to Table 4 show these programmes together with the number of relevant projects and the funding levels.

Table 2. Numbers and values of AF projects funded under FP7.

Funding action	Number of projects	Total funding (M€)	EU contribution (M€)
FP7-AAT - Aeronautics and air transport	1	16	9.4
FP7-ENERGY - Specific Programme "Cooperation": Energy	3	19.4	11.6
FP7-Environment - Environmental research under FP7	1	14	10.5
FP7-KBBE - Specific Programme "Cooperation": Food, Agriculture and Biotechnology	1	3.7	2.9
FP7-SPACE - Specific Programme "Cooperation": Space	5	12.7	9
FP7-SST - Sustainable Surface Transport	3	30.8	19.6
FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme (TPT)	27	222.3	136

Table 3. Numbers and values of AF projects funded under Horizon 2020.

Funding action	Number of projects	Total funding (M€)	EU contribution (M€)
Horizon2020 - Horizon2020 - The EU Framework Programme for Research and Innovation	12	81.8	70.9
H2020-EU.3.3. - Horizon 2020: SOCIETAL CHALLENGES - Secure, clean and efficient energy	10	96	N/A
H2020-EU.3.4. - Horizon 2020: Smart, Green and Integrated Transport	41	200.6	154.9

Table 4. Numbers and values of projects funded through other programmes.

Funding action	Number of projects	Total funding (M€)	EU contribution (M€)
CEF - Connecting Europe Facility[20]	52	912	284.7
ERA-NET - European Research Area Net	2	0.35	0.35
IEE - Intelligent Energy Europe	5	5.5	4.4
INTERREG Europe IV - INTERREG IV - Interregional cooperation across Europe (INTERREG IVC)	2	3.1	2.3
INTERREG IVB - INTERREG IV - Transnational programmes	4	10.8	7.1
LIFE - EU financial instrument supporting environmental, nature conservation and climate action projects	7	17.4	7.2
NWE - INTERREG IVB North West Europe (NWE) Programme	1	7.4	3.7
No funding programme identified	6	17.1	9.8

Between 2007 and 2013, the FP7 funded 41 projects relevant to alternative fuels with a total budget of €319 million. Projects funded under the 'Aeronautics, Energy' and 'Food, Agriculture and Biotechnology' actions focused on alcohol and synthetic paraffinic fuels, while those funded under the other actions covered methane-based fuels and LPG. From 2014, the Horizon 2020 programme funded 63 relevant projects equal to €378 million. Under these programmes, LPG fuel received little attention, while methane-based fuels, alcohols (with ethers and esters) and synthetic paraffinic fuels received similar levels of funding.

In addition to the two framework programmes, Table 4 shows that other EU programmes have also funded a number of projects. Connecting Europe Facility (CEF) is one of the most important programmes in terms of numbers of projects and value. The majority of projects funded under this action were focused on methane-based fuels, with a smaller amount of funding for alcohol fuels. Other funding actions equally covered all four types of alternative fuels.

4.3 Low-carbon alternative fuels in non-European countries' policies

To put European policies on low-carbon alternative fuels in context, it is useful to understand the status of similar international efforts. This section briefly reviews biofuel policies in ten non-European countries that have high carbon emissions (2014) from the transport sector based on the International Energy Agency's world development Indicators ([21]). Table 5 presents these emissions in percentage of total transport emissions and millions of tonnes (Mt).

Table 5. Transport CO_2 emissions for countries with highest levels

Country	Total CO_2 emissions (Mt)	Transport emissions (% total)	Transport CO_2 emissions (Mt)
United States	5 254.3	33.4 %	1 754.8

(20) Hydrogen related projects are not included.

(21) https://webstore.iea.org/co2-emissions-from-fuel-combustion-2018-highlights

Country	Total CO_2 emissions (Mt)	Transport emissions (% total)	Transport CO_2 emissions (Mt)
China	10 291.9	8.6 %	885.0
Russian Federation	1 705.4	16.2 %	277.0
India	2 238.4	11.5 %	256.9
Brazil	529.8	44.8 %	237.1
Japan	1 214.1	17.5 %	212.9
Canada	537.2	31.8 %	170.8
Mexico	480.3	35.1 %	168.5
Iran, Islamic Rep.	649.5	24.9 %	161.9
Saudi Arabia	601.1	25.9 %	155.8

Source: Analyses of data from International Energy Agency 'World development Indicators – Highlights 2018" (https://webstore.iea.org/co2-emissions-from-fuel-combustion-2018-highlights)

In 2009, California (USA) was the first state to pass a low-carbon fuels standard. The standard aims to reduce the carbon intensity of transport fuels sold in the state by 20 % by 2030. It operates through a 'cap and trade' system, with the cap reducing steadily over time. Fuels with carbon intensities below the cap generate credits, while those above the cap generate deficits and a requirement to purchase credits. A number of fuel types are exempt from the standard, including conventional aviation fuels and fuels for interstate locomotives and ocean-going vessels. Following the development of the California standard, the US Environmental Protection Agency (USEPA) introduced a Renewable Fuel Program ([22]) to promote renewable fuels to replace conventional transport fuels. The fuels in the Renewable Fuel Program include biomass-based diesel, cellulosic biofuel, advanced biofuel and total renewable fuel. The program includes a target of 36 billion (US) gallons of renewable fuel by 2022.

China is also promoting the use of alternative fuels for transport. The China Petroleum and Chemical Corporation, the largest oil refiner in China, plans to increase its involvement in biofuels ([23]). Since 2016, the company has produced diesel fuel with a 5 % biofuel content (B5) and is selling it commercially alongside other fuels. In 2017, the National Development and Reform Commission and the National Energy Administration announced plans to promote the use of ethanol blended with gasoline for cars across the country by 2020. They plan to make E10 (10 % ethanol) available, with large-scale production of cellulosic ethanol expected to be in place by 2025.

Russia is implementing climate legislation to regulate carbon emissions ([24]). However, the legislation will not include specific targets for individual sectors and there has been no indication of any promotion of alternative fuels for transport.

In May 2018, the Indian state of Rajasthan ([25]) was the first state to implement a national policy on the use of biofuels ([26]). The new policy expanded the scope of feedstocks used for producing biofuels to include sugar-containing materials (e.g. sugar beet), starch containing crops (e.g. cassava) and damaged food grains and potatoes unfit for human consumption. The policy also offers financial support to bio-refineries involved in producing advanced biofuels.

(22) https://www.epa.gov/renewable-fuel-standard-program
(23) https://www.telegraph.co.uk/china-watch/technology/what-is-biofuel/
(24) https://www.climatechangenews.com/2019/03/22/russia-floats-first-law-regulate-carbon-emissions/
(25) https://www.thehindu.com/todays-paper/tp-national/tp-otherstates/rajasthan-first-state-to-implement-biofuel-policy/article24568039.ece
(26) http://pib.nic.in/newsite/PrintRelease.aspx?relid=179313

For some time, Brazil has promoted the use of bio-ethanol derived from sugar cane for car fuel with up 100 % blends (i.e. pure ethanol). The policy was initially introduced to reduce dependence on oil imports but is now used to meet Brazil's obligations under the Paris Agreement ([27]). The RenovaBio programme aims to reduce gasoline emissions by over 10 % by 2028. This includes incentivising fuel distributors to increase the biofuel content of the fuels that they sell. The regulation centres on tradable carbon credits, based on the reductions in emissions represented by the individual biofuels. However, the required certification processes are still to be developed.

In July 2018, Japan published its fifth strategic energy plan ([28]). The plan highlighted a heavy reliance on imported oil for transport and recognised the need to diversify transport fuels. Japan had been heavily dependent on a single source (the Middle East) of LPG, but the increased availability of shale gas from North America had reduced this. The plan not only recognised the environmental benefits of LPG (over petroleum fuels) but also the importance of developing biofuels for cars. The Japanese government intends to introduce '*preferential measures for the introduction of the domestically-produced next-generation bioethanol*'. It will support first-generation bioethanol (based on food) where appropriate, future introduction of biodiesel, use of biofuels in aviation and of LNG and LPG in international shipping.

Since 2017, the Canadian province of British Columbia has had a low-carbon fuel standard, although both Ontario and the national government are considering similar actions ([29]). A national standard is expected to be implemented in 2022 ([30]). The standards specify the limits on carbon intensity that are required from the alternative fuels, but leave suppliers flexibility in which fuels to use to meet the standard. The initial national standard is expected to cover liquid fuels; followed by a similar standard for gaseous fuels.

(27) https://knect365.com/energy/article/e5560843-78a9-4034-81f7-25319afe103c/what-to-expect-from-brazils-renovabio-programme
(28) https://www.enecho.meti.go.jp/en/category/others/basic_plan/5th/pdf/strategic_energy_plan.pdf
(29) https://institute.smartprosperity.ca/sites/default/files/lowcarbonfuelstandards-web.pdf
(30) https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/CFS%20-%20Cost%20benefit%20analysis%20framework-EN.pdf

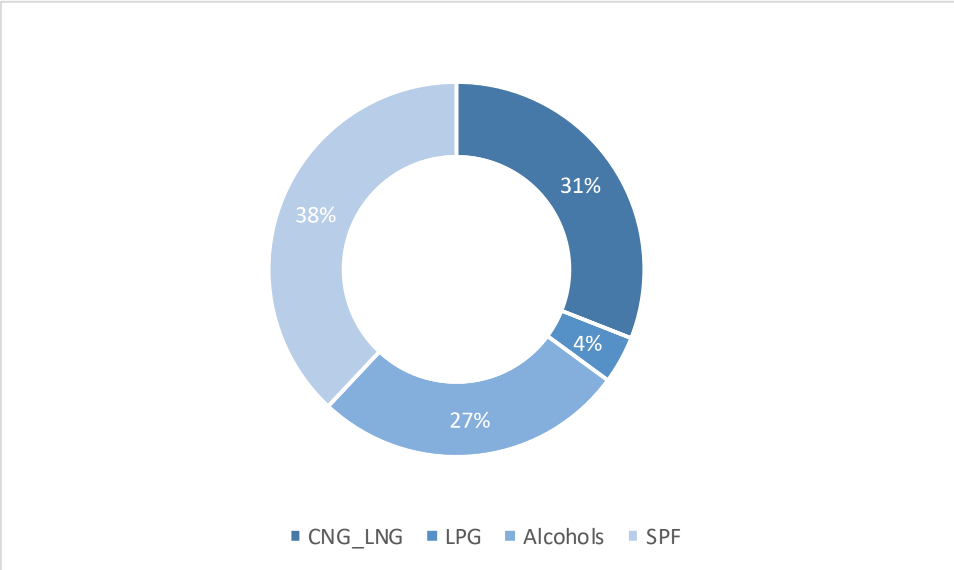
5 Projects and Technology assessment

This section provides a comprehensive analysis of AF research projects financed by the FP7 and H2020 framework programme. It analyses the top 15 technologies and the technology readiness level of the most relevant technologies identified. It also evaluates recent European funding calls and AF technology development across the EU. Annex 1 lists all projects reviewed in the analysis, which includes other funding calls such as CEF.

5.1 Framework programmes analysis

Over EUR 810 million have been invested under FP7 and H2020 in AF research projects. This includes EUR 610 million of EU funds and contributions from beneficiary organisations equal to EUR 200 million. Figure 3 shows how these research funds are divided between the different types of alternative fuels that are researched. SPFs receive 38 % of funding followed by methane based fuels with 31 % while LPG receives only 4 %.

Figure 3. Funding by fuel type

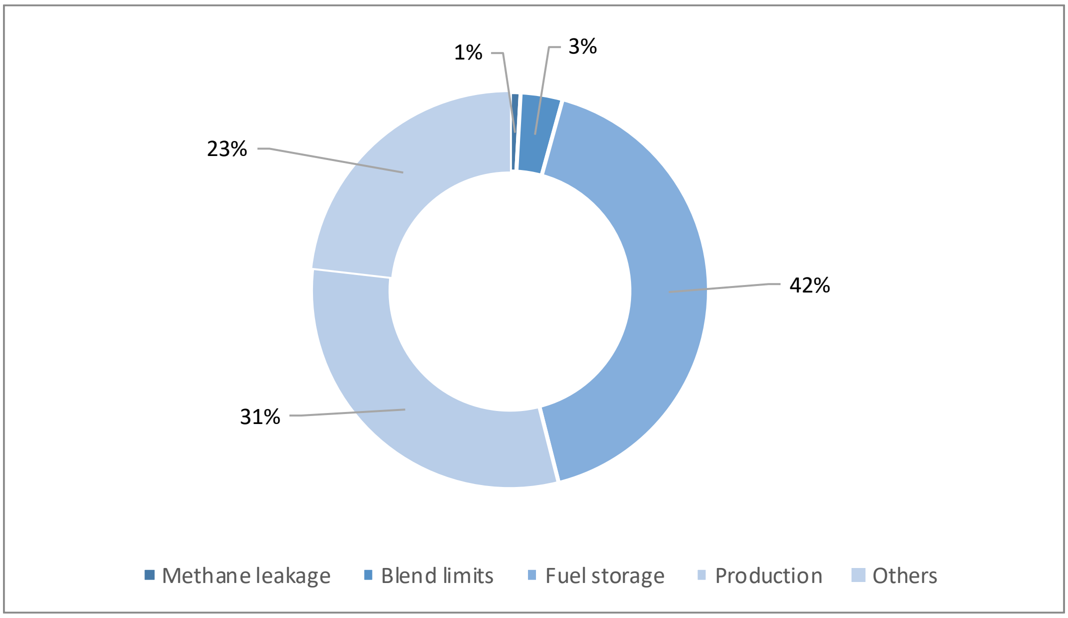


Source: TRIMIS (31).

A number of key challenges exist to the further development of alternative fuels. Figure 4 shows funding distribution by key development challenge. Two challenges dominate: fuel storage, handling and injection systems received 42 % of the funds while production of process scale, cost-effectiveness and lack of infrastructure received 31 % of the funds. Methane leakage and better understanding of blend limits received 4 % of the funds. Other key challenges, such as stakeholder engagement received the remaining 23 % of the funds.

(31) https://trimis.ec.europa.eu/

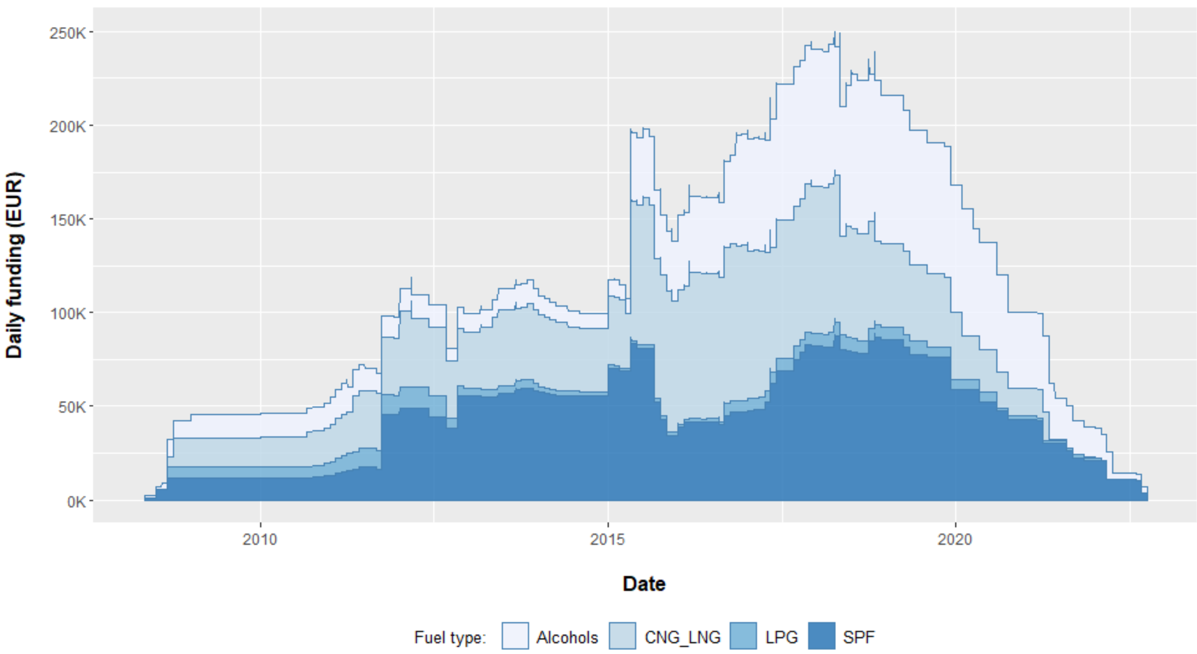
Figure 4. Funding by key development challenge



Source: TRIMIS.

Figure 5 expands on this information by showing funding trends since 2008, based on the average daily funding of research projects. It shows that H2020 increased the research budget compared to FP7. It is also noticeable that more funds are directed towards research on alcohol-based fuels. The daily research spending peaked in the first quarter of 2018 at approximately EUR 200 000. A funding forecast is also provided based on projects that were awarded by May 2019, meaning that the final funding may still be higher.

Figure 5. Daily research funding by fuel type

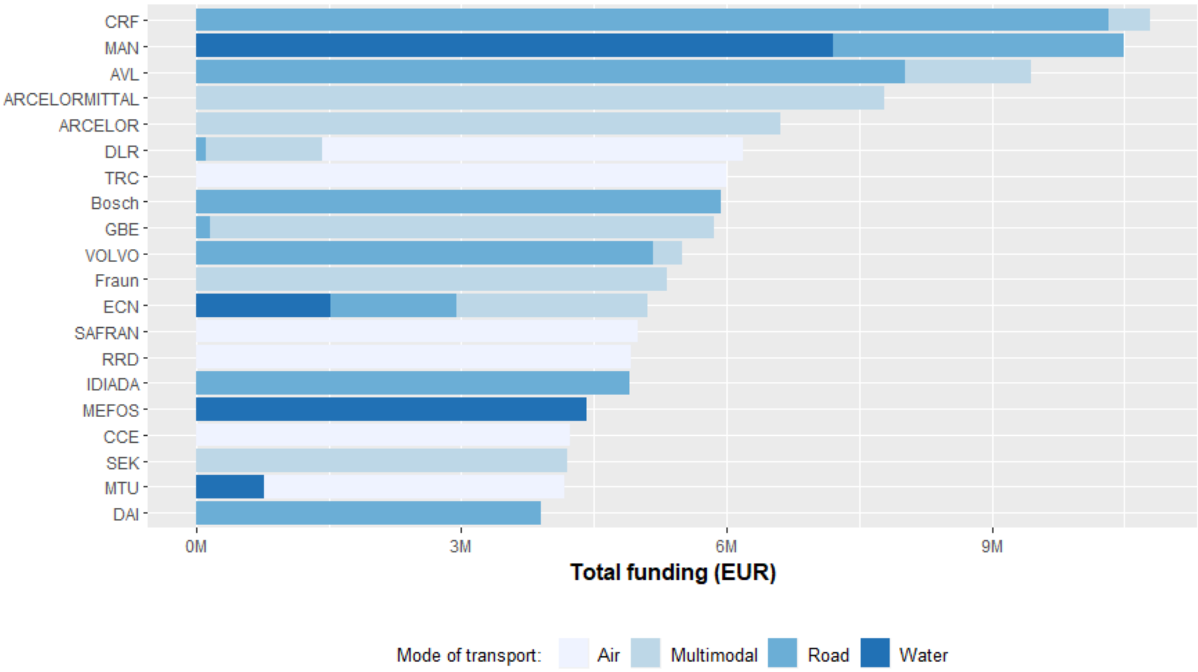


Source: TRIMIS.

5.2 Geographical and organisation analysis

A total of 823 unique organisations participated in FP7 and/or H2020 projects on AF. Figure 6 shows the top 20 beneficiaries with the total amount of funds received and their research focus in terms of transport mode. Some organisations focus exclusively on AF research for one transport mode, whereas others conduct research across a number of modes. Of the top 20 beneficiaries, 10 are active in road, 9 in multimodal, 6 in air, and 4 in waterborne transport.

Figure 6. Top 20 AF funding beneficiaries, including division between transport modes

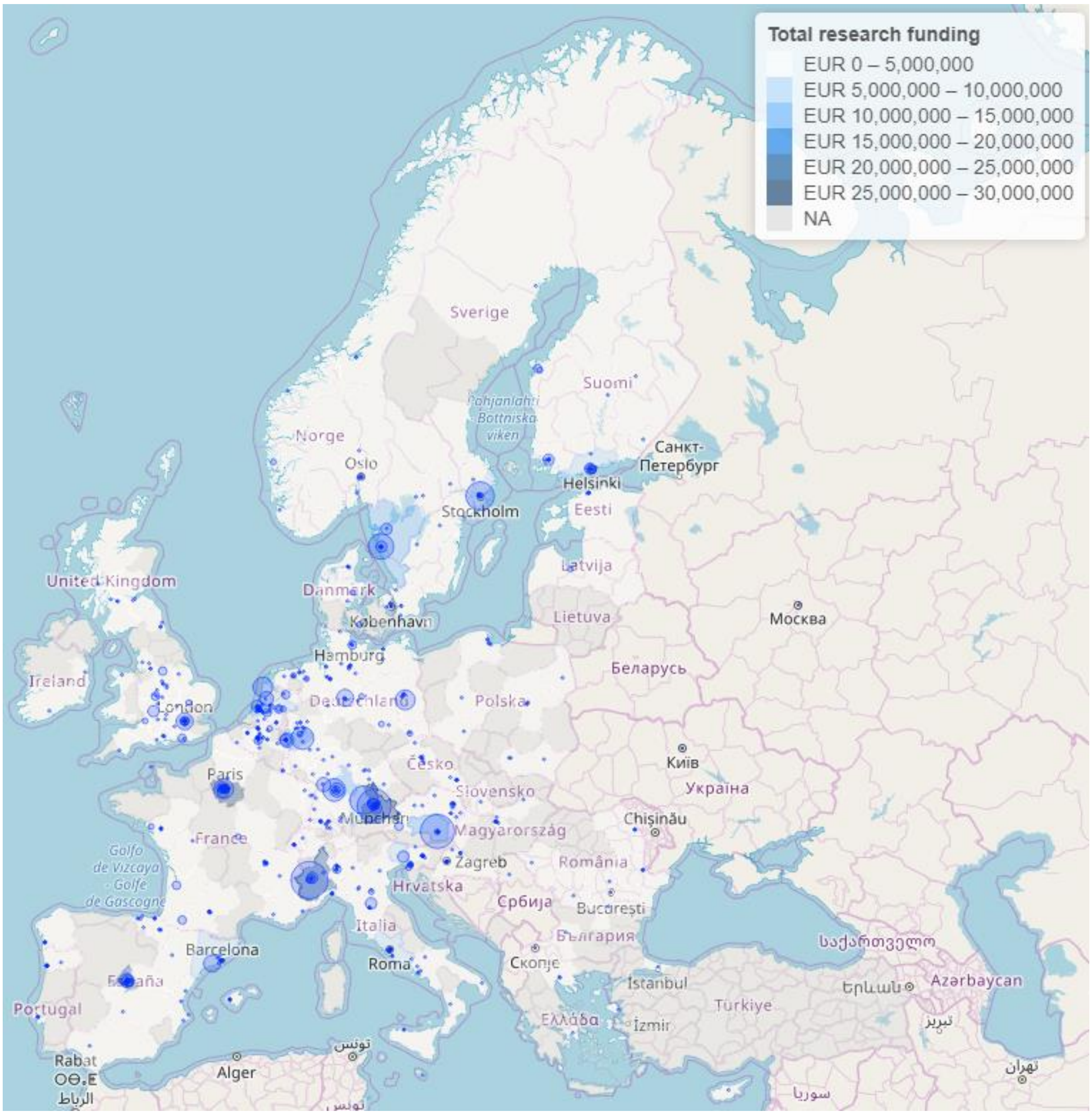


Source: TRIMIS.

The top 20 beneficiaries received approximately EUR 120 million of funding, which is approximately 19 % of the total AF funding budget. The funding concentration is therefore relatively low with funds spread across a large number of organisations. Figure 7 provides the geographical spread of the funds. Several beneficiaries in Germany, Italy and Sweden receive a large part of the funding, as indicated by the size of the circles. Most organisations are located in areas where large car manufacturers are present, such as Turin, Munich and Goteborg. Organisations from the EU-13 receive a smaller share of the funds.

The spending of research funds may occur in a different location than where a beneficiary is registered. This could happen when pilot studies are undertaken at different sites. However, the map provides a reasonable approximation of where resources are allocated.

Figure 7. Location of AF funding beneficiaries

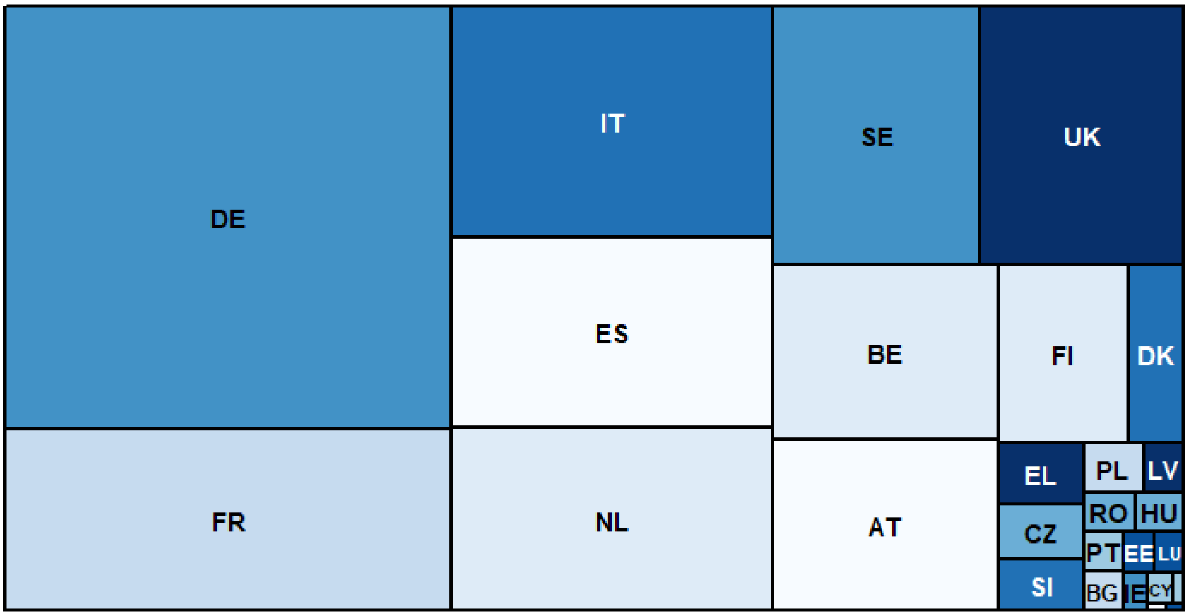


Source: TRIMIS.

5.3 Member State analysis

An assessment of FP7 and H2020 AF research in terms of funds received by Member State, based on the beneficiary's address, shows that Germany is the largest beneficiary in absolute terms, followed by France (see Figure 8). Figure 7 also shows the imbalance in funding for organisations based in EU-13 countries.

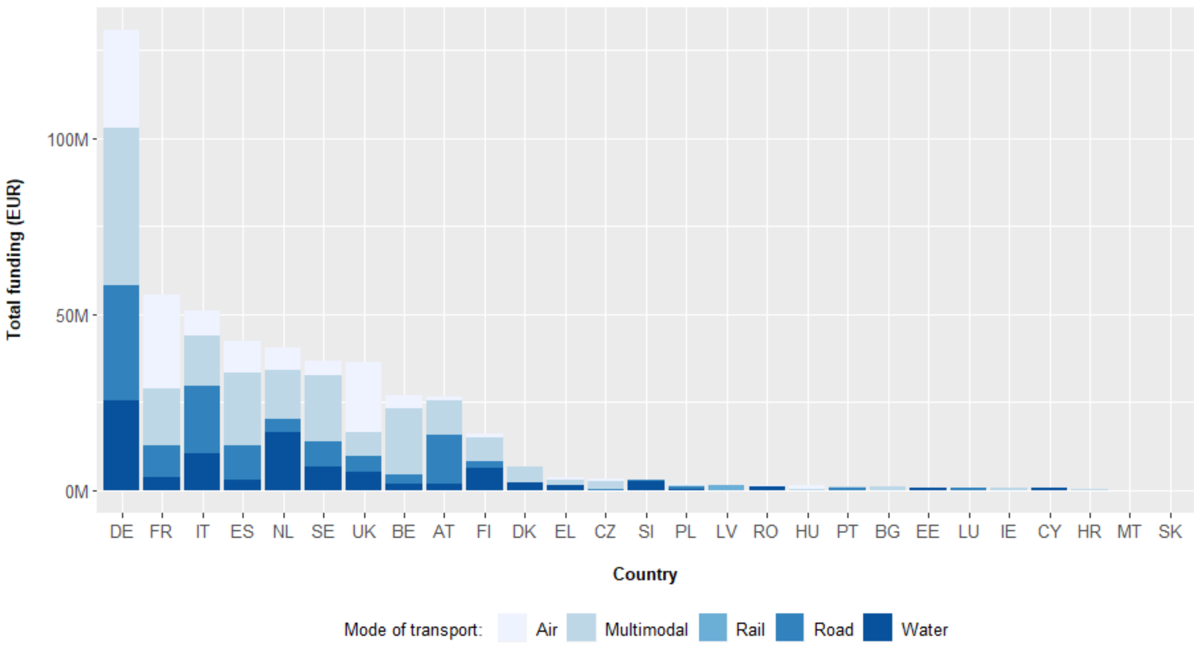
Figure 8. MS shares of AF funding



Source: TRIMIS.

Figure 9 provides a detailed overview on AF research funding, showing the total amount of funding received by Member State according to transport mode. Organisations from Croatia, Malta, and Slovakia had a particularly low participation level in this field.

Figure 9. AF funding by MS, including division between transport modes

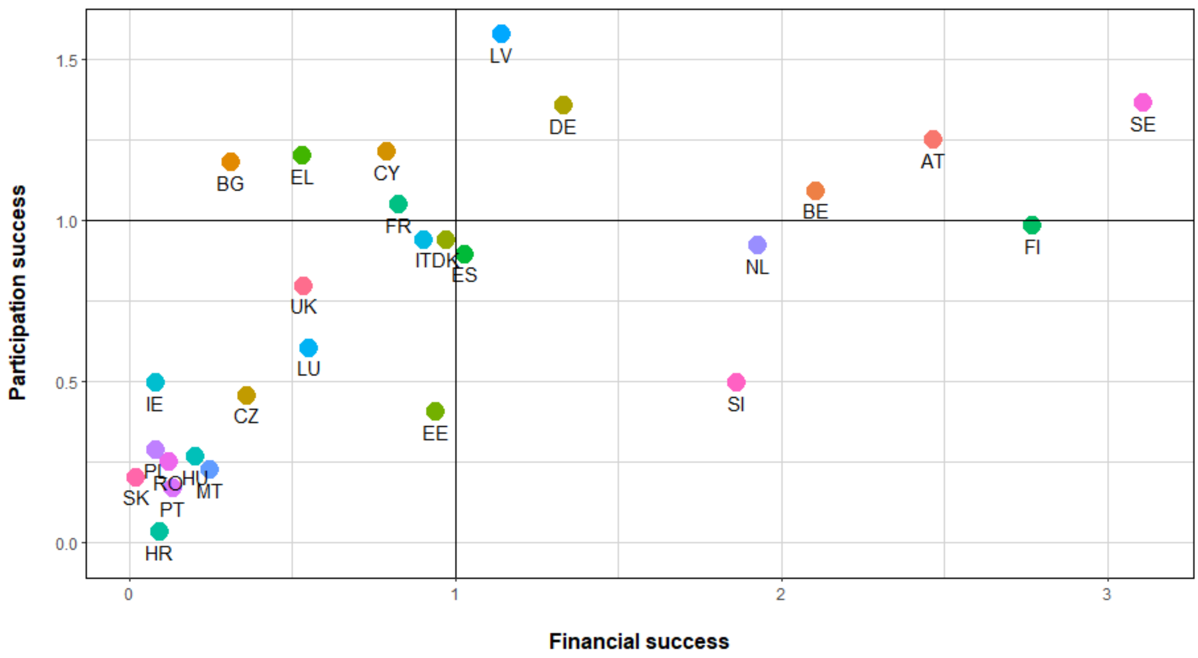


Source: TRIMIS.

To understand the relative performance of Member States, participation and financial success rates are normalised based on 2016 Gross Domestic Product (GDP). The participation success rate assesses the involvement of organisations from one Member State compared to the total participation. Similarly, the financial success rate assesses the total amount of granted funds per Member State as compared to the total AF R&I funding. A score of one indicates an average performance, with scores above or below one being better or worse respectively.

Figure 10 shows a few strong performers in terms of participation and financial success, notably Sweden, Austria, and Latvia. A number of countries in the lower right quadrant succeed in attracting larger funds with relatively fewer organisations. This may be indicative of expert organisations in these Member States. The lower left corner shows a large number of countries involved less in FP-funded AF research relative to what could be expected from a Member State based on its size in terms of GDP.

Figure 10**.** Participation and financial success rate of Member States



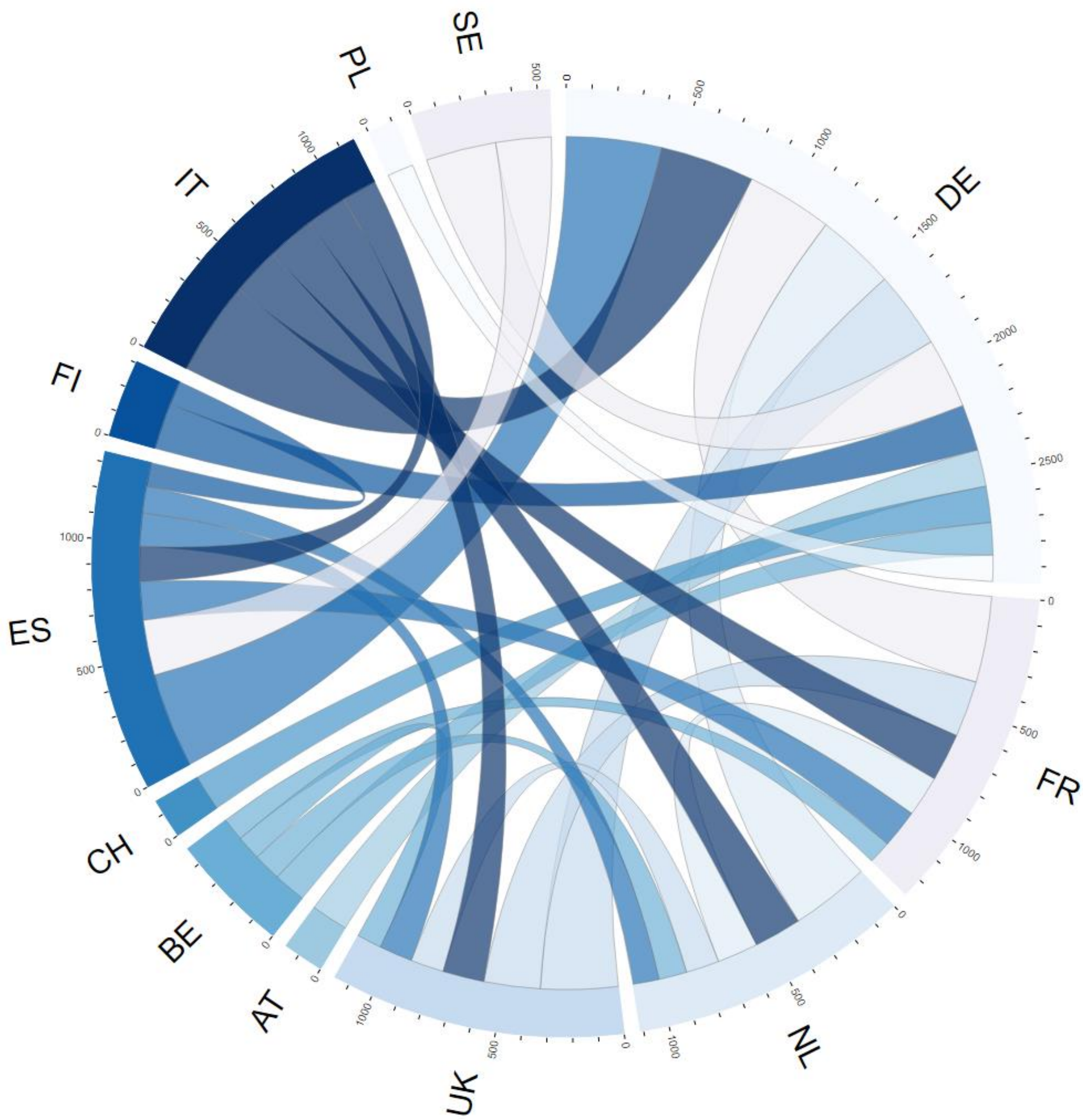
Source: TRIMIS.

A large number of organisations from various countries participate in many projects. These can be aggregated on a Member State level to show which countries collaborate in the field of AF.

Figure 11 highlight common collaborations between organisations from Member States that occurred at least 100 times. The figure counts each time two organisations based in different countries cooperate. For example, if in a project one Spanish and two Austrian organisations collaborate, the link between Austria and Spain gains a strength of two. These numbers are added together for all projects. The colours are indicative of the country, whereas the width of the cords is indicative of the number of collaborations. Eight Member States exceed 100 organisational collaborations. Organisations from other Member States also actively collaborate, but these ties are not visualised, as they do not cooperate more than 100 times. The analysis therefore focuses on absolute, rather than the normalised performance as was used in Figure 10.

A few observations can be shared. Unsurprisingly, larger EU countries are the most visible in the chart. It equally shows that Dutch organisations have strong relations with Germany and Italy in the field of AF research. Although not such a big country, organisations from Belgium are also present in the collaboration network. A potential explanation is the presence of many Brussels based associations in the field of transport and energy.

Figure 11. Chord diagram on Member State collaborations in FP7 and H2020 AF projects



Source: TRIMIS.

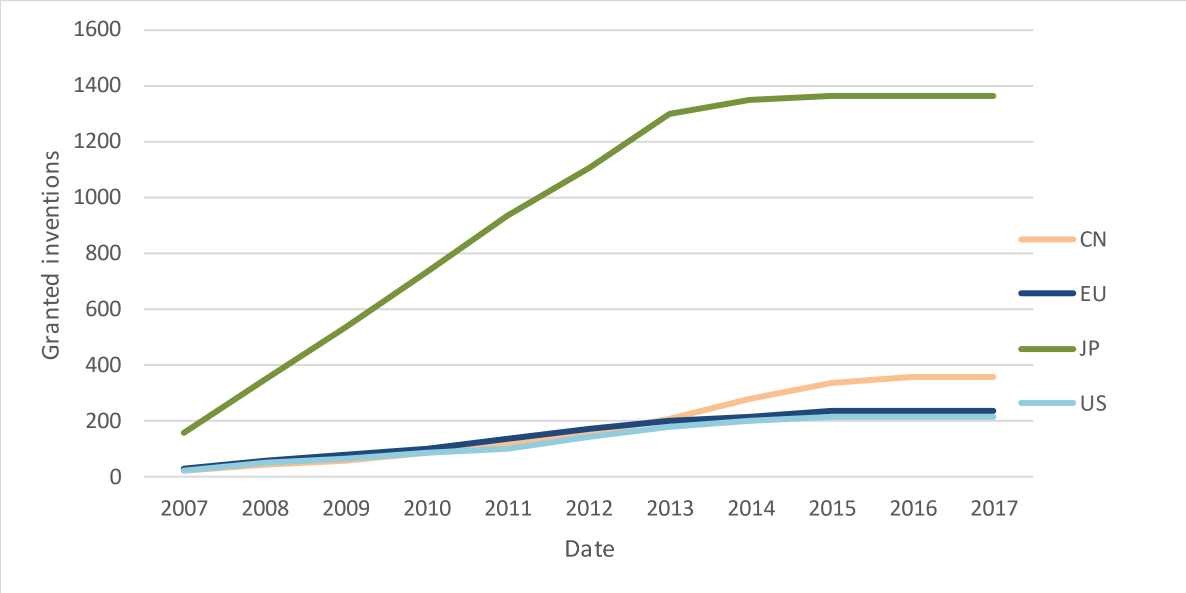
5.4 Patent analysis

Figure 12 provides an insight into the relative interest and strength of various regions in research on alternative energy. The figure is based on the PATSTAT 2018 spring dataset ([32]), which covers information on international patent applications. In line with Fiorini et al. (2017), the methodology ensures consistency and relevance of the data.

Figure 12 shows that Japan is the most active in terms of patenting innovations in alternative energy. China is increasingly interested in the field, which is likely to become evident over the coming years, as the coverage of patent data has a delay of 1 to 3 years.

(32) https://www.epo.org/searching-for-patents/business/patstat.html#tab-1

Figure 12. Alternative energy inventions granted by region (cumulative count)



Source: TRIMIS.

5.5 Top technologies identified in the roadmap

The analysis presented here focuses on the overall 'top 15' technologies identified for the STRIA alternative energy for transport technologies roadmap. The radial structure of Figure 13 highlights the key metrics of the top 15 technologies.

The metrics analysed here are:

— "Number of projects": the number of projects that have researched the technology;

— "Value of projects per technology": the total value of all projects that have researched the technology (i.e. the total investment, by both the EU and industry, in the development of the technology);

— "Number of organisations": the number of organisations that have been involved in projects that have researched the technology;

— "Number of projects organisations are involved in": the total number of projects that the organisations (identified as having been involved in projects researching the particular technology) have been involved in.

The first two metrics highlight the combined effort put into the technology while the third and the fourth proxy the level of interest in the technology in industry and academia, indicating available capabilities to bring the technology to market. By linking several technology metrics with organisational data, it is possible to identify technology value chains, including opportunities, as well as providing an indication of overspending and inefficiencies.

Figure 13. Top 15 AF technologies

Source: TRIMIS.

Bars not in scale. Abbreviations: AF - Alternative Fuels; CC - Combustion Chamber; RD - Renewable Diesel; PF - Particulate Filter; CNG - Compressed Natural Gas; TWC - Three-Way catalyst; FT - Fischer-Trop method; FI- Fuel injection

5.6 Technology readiness levels in the roadmap

In the 1970s, NASA developed the technology readiness level (TRL) to estimate the maturity of technologies during the acquisition phase of a programme ([33]). In 2010, the EC recommended EU-funded research and innovation projects adopt the TRL scale, which was subsequently used in the EU Horizon 2020 programme. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology. Table 6 describes each TRL ([34]) and the corresponding development phases used in TRIMIS.

In TRIMIS, the nine TRLs have been consolidated into four development phases: research/invention; validation; demonstration/prototyping/pilot production; and implementation. These describe the maturity of each technology similar to the original TRL scale.

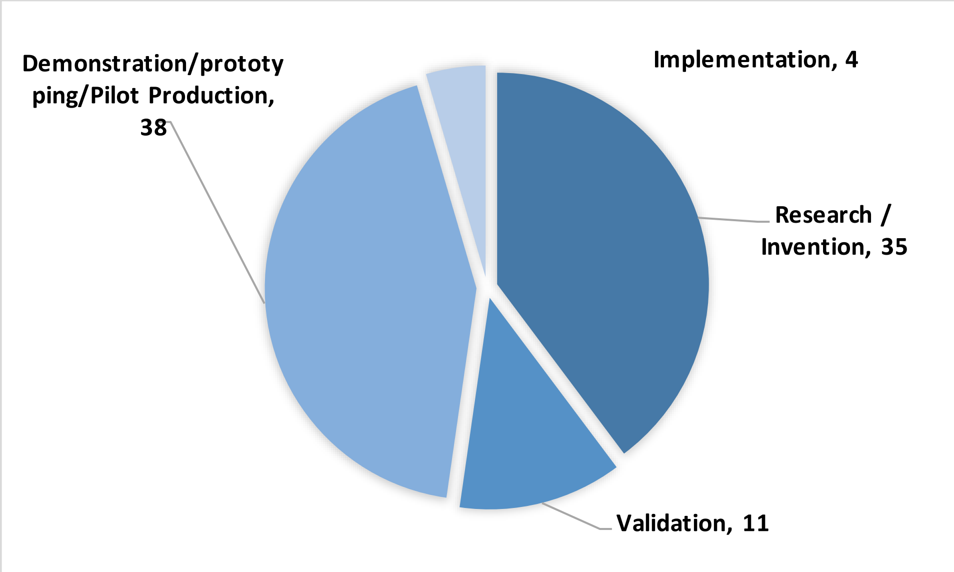
Table 6. TRL and TRIMIS development phases

TRL level	Description	TRIMIS development phase
TRL 1	Basic principles observed	Research /invention
TRL 2	Technology concept formulated	
TRL 3	Experimental proof of concept	Validation
TRL 4	Technology validated in lab	
TRL 5	Technology validated in relevant environment	Demonstration/prototyping/pilot production
TRL 6	Technology demonstrated in relevant environment	
TRL 7	System prototype demonstration in operational environment	
TRL 8	System complete and qualified	Implementation
TRL 9	Actual system proven in operational environment	

Table 7 shows that 88 of 177 AF TRIMIS projects (see Annex 1) link to some type of technology and development phase. This means that a project can count more than once, if it links to two technologies. A total of 35 projects (almost 40 % of the 88 projects) are at the research/invention phase, 11 projects (12.5 % of the projects) at the validation phase, 38 (43 %) at the demonstration/prototyping/pilot production phase, and the remaining 4 (almost 5 %) at the implementation phase. A deeper analysis of the table shows that LPG does not appear in any of the projects. This means that LPG has no technology linked in any research project. A potential reason for this is that LPG is a consolidated technology in the market. In the long-term, other fuels have a better environmental performance. A total of 26 of the projects research LNG refuelling stations, with 21 of them in the demonstration/prototyping/pilot production development phase, which means LNG refuelling technology is under research and in final stages before commercialisation. Finally, few technologies are in the implementation phase, which means that is difficult to forecast any relevant change in the technologies of alternative fuels in the future (see Figure 14). Figure 15 shows technology projects distribution by transport mode. As expected, road transport dominates the picture.

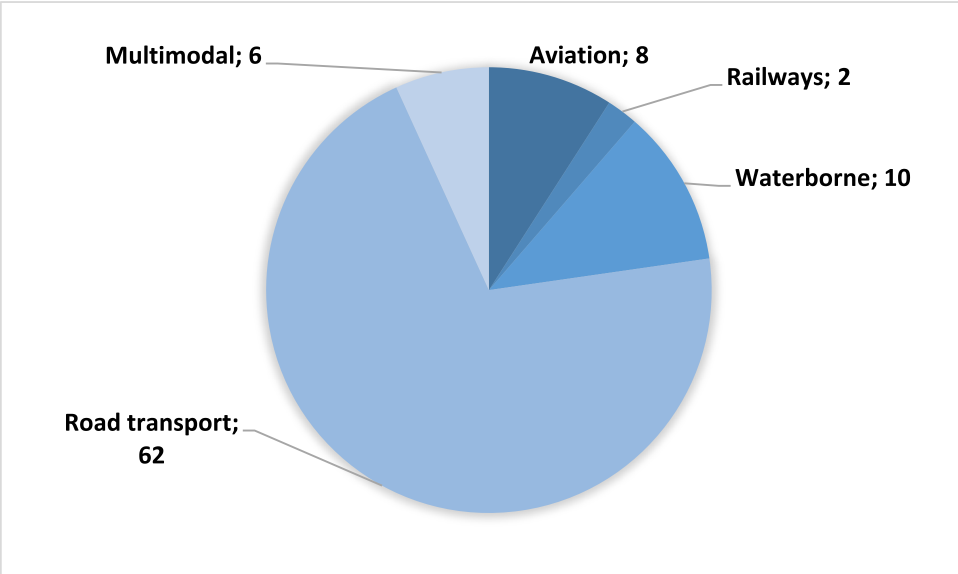
(33) https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html
(34) https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

Figure 14. Summary of AF Development Phase



Source: TRIMIS.

Figure 15. Technology projects distribution by transport mode



Source: TRIMIS.

Table 7. Technologies ranked by their development phase

Development Phase	Technology	Number of projects	Main Project and FP Programme
Research/invention	Alternative aviation fuels	2	BIO4A – H2020
Research/invention	Combustion chamber for diesel/ethanol blend characterisation	2	BEAUTY – FP7

Development Phase	Technology	Number of projects	Main Project and FP Programme
Research/invention	Fuel injection system and cold start electrical device	1	BEAUTY – FP7
Research/invention	Aviation alternative fuel production using Fischer-Tropsch method from synthetic gas	1	SOLAR-JET – FP7
Research/invention	Simulation model for terminal energy consumption and supply	1	GREEN EFFORTS – FP7
Research/invention	Multi-fuel ship propulsion	2	NEWS – FP7
Research/invention	CNG engine with integrated auxiliaries	1	GASTONE –FP7
Research/invention	Alternative aviation fuels	1	GRAIN 2 – FP7
Research/invention	Selective catalytic reduction and particulate matter filters	1	JOULES – FP7
Research/invention	Waste heat recovery system	1	JOULES – FP7
Research/invention	LNG refuelling station	1	LNG Blue Corridors – FP7
Research/invention	LNG truck	1	LNG Blue Corridors – FP7
Research/invention	Fuel-flexible engines and systems	1	HERCULES-2 – H2020
Research/invention	CNG mono-fuel engine	1	GasOn – H2020
Research/invention	Low precious metal content 3-way catalyst	1	GasOn – H2020
Research/invention	Heavy duty engine design for alternative fuels	1	HDGAS – H2020
Research/invention	Emissions evaluation of renewable diesel in rail	2	NYSMART – H2020
Research/invention	Ship design for CNG transport	1	GASVESSEL – H2020
Research/invention	Heavy duty engine design for alternative fuels	1	optiTruck – H2020
Research/invention	LNG conversion	1	BLUESKY – H2020

Development Phase	Technology	Number of projects	Main Project and FP Programme
Research/invention	Biofuels for road transport	4	NextGenRoadFuels – H2020
Research/invention	CNG fuelling station	1	Green Connect - A public CNG network – CEF
Research/invention	Biomethane from waste system	3	WASTE2FUELS – H2020
Research/invention	Conversion kit for alternative fuels	1	eForFuel – H2020
Research/invention	Biofuels for road transport	2	BioMates – H2020
Validation	Waste heat recovery system	1	NOWASTE – H2020
Validation	Alternative aviation fuels	2	ITAKA – H2020
Validation	Biofuels for road transport	5	Torero – H2020
Validation	LNG refuelling station	2	BESTWay - CEF
Validation	Biomethane from waste system	1	ButaNexT – H2020
Demonstration/prototyping/pilot production	LNG truck	2	Cryoshelter – H2020
Demonstration/prototyping/pilot production	Retrofit solution for Euro 6 engines	1	E6 Evolution – H2020
Demonstration/prototyping/pilot production	Heavy duty engine design for alternative fuels	1	HDGAS – H2020
Demonstration/prototyping/pilot production	Fuel modifiers	1	GreenDrive – H2020
Demonstration/prototyping/pilot production	Conversion kit for alternative fuels	1	InjectoReducer – H2020

Development Phase	Technology	Number of projects	Main Project and FP Programme
Demonstration/prototyping/pilot production	Waste heat recovery system	2	TORC – H2020
Demonstration/prototyping/pilot production	Alternative aviation fuels	2	BIO4A – H2020
Demonstration/prototyping/pilot production	Biofuels for road transport	4	STEELANOL– H2020
Demonstration/prototyping/pilot production	LNG refuelling station	21	BIOLNG4EU – CEF
Demonstration/prototyping/pilot production	LNG conversion	2	LNGHIVE2 – CEF
Demonstration/prototyping/pilot production	Biomethane from waste system	1	FReSMe – H2020
Implementation	LNG truck	2	LNG Logistics - CEF
Implementation	Diesel solution applying electric pulsed power technology	1	AQUASONIC-diesel – H2020
Implementation	LNG refuelling station	1	GREAT – CEF

6 Research and innovation assessment

This section presents an analysis of the research undertaken, results achieved and the implications for future research and policy development, under four sub-themes. In line with the fuel categories included in the low-carbon alternative fuels roadmap, the sub-themes selected for this analysis are:

— methane-based fuels (CNG, LNG and bio-based equivalents);

— LPG (and bio-based equivalents);

— alcohols, ethers and esters;

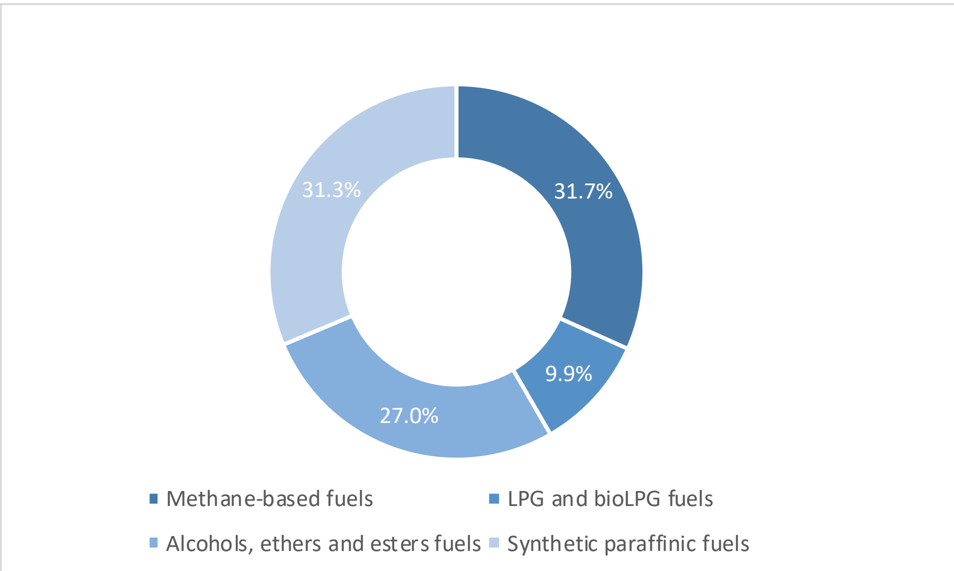
— synthetic paraffinic fuels.

Table 8 shows the numbers of projects and levels of funding identified from an analysis of the projects in TRIMIS under each of these sub-themes. Figure 16 provides percentage funding by fuel. The percentages shown in Figure 3 and Figure 16 are similar since the former considers only FP7 and H2020 whereas the latter includes other European programmes.

Table 8. Alternative fuel type summary table.

Alternative fuel type	Total project value (M€)	Total EU contribution (M€)	Number of projects
Methane-based fuels	504.6	315.8	90
LPG and bioLPG fuels	158.1	104.7	38
Alcohols, ethers and esters fuels	429.6	281.7	77
Synthetic paraffinic fuels	498.5	319.6	84

Figure 16. Total funding by type of fuel



Source: TRIMIS.

In addition to the division of research projects by fuel type, it is possible to assess the number of projects and levels of funding by funding source (see Table 9). Where a project researches multiple fuels (and, therefore, is counted multiple times in the former Table 8), each project is counted under only one funding source in Table 9.

Table 9. AF research by parent programme summary.

Alternative fuel type	Total project value (M€)	Total EU contribution (M€)	Number of projects
Horizon 2020	378.4	225.7	63
FP7	319	198.9	41
CEF - Connecting Europe Facility	912	284.7	52
ERA-NET - European Research Area Net	0.35	0.35	2
IEE - Intelligent Energy Europe	5.5	4.4	5
INTERREG	21.3	13.1	7
LIFE	17.4	7.2	7

Horizon 2020 and FP7 have each funded a similar level of research in alternative fuels (over € 300 million). The Connecting Europe Facility (CEF) programme has funded approximately three times this value of projects, although many of those are large-scale infrastructure developments and are on a different scale to the majority of research discussed in this report; the other EU programmes fund less research relevant to the AF roadmap.

6.1 Methane-based fuels

This section covers the use of all methane-based fuels, principally compressed natural gas (CNG) and liquefied natural gas (LNG). There is also research into biomethane as a transport fuel. Biomethane has lower carbon emissions compared with petrol or diesel due to the lower carbon content of the fuel ([35,36]). However, recent research suggests NG engines might have higher particle number (PN) emissions than diesel engines; which remains a crucial issue to be addressed if gaseous fuels are introduced as a viable alternative to diesel. The research projects in this area generally focus on issues such as the development of engine technology, fuel storage and charging infrastructure.

6.1.1 Overall direction of R&I

Projects focusing on LNG fuel target high-powered vehicles such as LNG trucks or alternative propulsion for ships. As electrification is a long-term solution for heavy vehicles, research on LNG is being undertaken to offer a low-carbon alternative to diesel. There is little research in the aviation sector regarding methane-based fuels, as other fuels are more promising. In the rail sector there is new research into using a dual-fuel system for locomotive propulsion with either LNG or CNG. As this technology is at early stage, future technologies with methane-based fuel for rail could attract funding in the future. Currently, there is some exploration of methane-based fuels in maritime transport, mainly to do with fuel storage and the transport of LNG/CNG.

LNG is the dominant methane-based fuel in terms of number of projects and total funding. The ongoing research suggests that LNG heavy-duty road vehicles are at a high TRL with demonstration of natural gas engines and storage in the field. Research and innovation indicate that an optimal refuelling infrastructure is needed to commercialise LNG HDVs within the EU.

CNG research is only seen in road transport, specifically for passenger cars and light-duty vehicles. The focus is on engine design and refuelling stations. Research is proving that CNG can reduce overall carbon emissions, if methane leakage is addressed, and NOx emissions while maintaining petrol-like performance levels for light vehicles. However, three recent projects (PEMSFORNANO, DOWNTOTEN and SUREAL 23) show that when considering the smallest particles, CNG vehicles might emit more pollutants than conventional vehicles. Projects

(35) Biomethane in Transport; European Biogas Association; 2016 http://european-biogas.eu/wp-content/uploads/2016/05/BiomethInTransport.pdf
(36) Can natural gas reduce emissions from transport? Sustainable Gas Institute; 2019 https://www.sustainablegasinstitute.org/wp-content/uploads/2019/01/SGI_White_Paper_Briefing_note_2019_v3-1.pdf

are also exploring the possibility of blending biomethane with CNG, which achieves close to zero well-to-wheel emissions.

Biomethane has lower carbon emissions than LNG or CNG and could therefore attract increased research funding in the future. Current research into biomethane suggests that the economics of production and distribution of the fuel is of importance if it is to be used as an alternative transport fuel source. However, it should be noted that if the infrastructure and technologies are in place for CNG and LNG fuels, then it would be much easier to replace these with the more sustainable biomethane.

6.1.2 R&I activities

The projects included in this sub-theme assessment have undertaken research into a range of methane-based alternative transport fuels. Table 10 shows that there is considerable funding and projects regarding LNG compared to CNG and biomethane-specific projects. This could be due to the larger scale of the LNG projects and the LNG TRL compared to biomethane as a fuel type.

Table 10. Methane-based alternative fuel type summary table

Fuel type	Total project value (M€)	Total EU contribution (M€)	Number of projects	Average project value (M€)
LNG	133	77.6	20	6.6
CNG	43.2	28.1	6	7.2
LNG/CNG	0.14	0.1	2	0.07
Biomethane	33.1	24.3	10	3.3
Not specified / mixture of fuels	295.2	185.8	52	5.7
Total	504.6	315.8	90	5.6

A selection of research projects on methane-based alternative transport fuels is presented below. These projects are examples of innovation in methane-based fuels and are complete with well-reported results.

— The DiGas (2016-2017) project aimed to accelerate diesel locomotive market transition from oil-based diesel fuel to cheaper, cleaner and much more sustainable methane in the form of LNG or CNG. The first phase investigated risks and hurdles to the commercialisation of natural gas. Based on a feasibility study, the project developed a strategy to raise the technology from TRL 6 to TRL 9, which is crucial for the market rollout of the technology and the development of a business case for a shift to cleaner and cheaper engines. DiGas SIA developed NYSMART (2017-2019); a proprietary patented dual-fuel technology for rail locomotives. Due to its modular form, NYSMART can be quickly and simply installed onto any type of diesel engine. By addressing the current limitations of existing technologies, the NYSMART project delivered a business plan to generate revenue and return on investment. By 2024, the aim is to have addressed 3.6 % of the available European locomotive market.

— GasOn (2015-2018) and INGAS (2008-2012) had similar aims – to exploit the main benefits of gas-powered engines by developing dedicated CNG-only engines for both passenger cars and light-duty goods vehicles (LGVs). INGAS developed technology to allow for 65 % biomethane/35 % CNG gas blend to be used in a CNG engine, with the potential to achieve near zero well-to-wheel emissions. Meanwhile, GasOn researched and demonstrated the potential of CNG engines for current and future light vehicles. The results from GasOn showed that petrol-like performance and driving range, low NOx emissions and halved carbon emissions (compared to current petrol vehicles) are feasible and affordable.

— The MDC (2016) project research the possibility of building stations fuelling large numbers of CNG trailers simultaneously. This project used a 'mother-and-daughter' concept by having high pressure 'mother' stations providing cheap gas to CNG trailers which then fuel vehicles at 'daughter' stations located where customers want them. The phase 1 feasibility study identified two suitable sites for a pilot project. Phase 2 is ongoing and the study is moving towards testing the concept in the real world.

- HDGAS (2015-2018) and LNG Blue Corridors (2013-2017) focused on the use of LNG as an alternative fuel. HDGAS aimed to provide a breakthrough by integrating gas engines into HDVs. The technology is expected to deliver CO_2 emissions that are 10 % lower than the current state of the art. LNG Blue Corridors built 14 LNG refuelling stations across Europe and is embarking on a demonstration project involving 100 LNG HDVs. Liquefied biomethane will also be tested to investigate the potential of higher CO_2 savings.
- The project LNG for shipping and logistics in Europe started in March 2016 and will be completed by 2019. It is funded by CEF programme. It aims to promote LNG by helping the development of the TEN-T Rhine-Alpine corridor. In order to achieve that goal, there are two specific objectives. Firstly, to gain knowledge about the potential of LNG markets in Germany and Austria. Secondly, to increase the LNG availability in the Rhine for inland navigation and road transport.
- Gasvessel (2017-2021) aims to prove the techno-economic feasibility of a new CNG transport concept. It will use a recent patented pressure vessel manufacturing technology, and a novel conceptual ship design addressing safety on- and off-loading solution. The project will reduce energy dependency on imports as it will supply CNG to places where is not available such as the Mediterranean Islands. The financial and economic viability of these advancements will be assessed.
- HERCULES-2 (2015-2018) is part of a long-term R&D programme that targets the development of a fuel-flexible large marine engine. The dual-fuel combustion engine uses alternative fuels (such as LPG and LNG) in a lean pre-mixed combustion process with a pilot diesel flame for ignition. In particular, this has been shown to limit NOx and soot emissions.
- Methane slippage is a major problem for engines of inland waterway vessels with dual-fuel engines. NONOX (2014-2016) developed a throttle-free load control system that improves the efficiency of dual-fuel engines in terms of methane slippage. This technology has already been beneficial to city buses using LNG, and now the 'Throttle-free natural gas engine' project (2014-2016) has tested this on inland vessels.
- There is little activity in the aviation sector for methane-based alternative fuels. ACEP (2015-2017) utilised inert lifting gas to reduce the fuel burn compared to a conventional aircraft. However, this is the only use of gas in the aviation sector currently being researched. Other alternative fuel types are showing more promise than the methane-based fuels due to concerns over design and safety.

6.1.3 Achievements

Several European funded projects are improving current state-of-the-art technology for methane-based fuels in transport. The results of these projects are shown below.

Significant progress has been made in the development of natural gas engines, helping to demonstrate the reduction in carbon emissions from using pure natural gas engines compared to diesel and petrol counterparts. Research has shown that HDVs using natural gas engines can meet the latest emission standards.

- HDGAS (2015-2018) achieved the objective of meeting a 10 % carbon emission reduction compared to state-of-the-art technology and showed a range of 800 km for a pure natural gas engine in a long-haul HDV (around the 40-tonne range). A high-pressure gas injection engine (HPDI) achieved a 20 % reduction in carbon emissions and complied with Euro VI emission standards. Additional achievements were an efficiency comparable to state-of-the-art diesel, negligible NO and soot emissions, and Euro VI standards were met without methane after-treatment.

LNG storage tanks have achieved a high TRL by demonstrating technical and economic viability, while putting LNG tanks on the road.

- Cryoshelter (2015-2017) focused on bringing the Cryoshelter second generation LNG tank technology to industrial readiness. The product design was brought from prototype to series design that included the development of an assembly rig to prove that the technology can be industrialised. The primary objective of this project was to verify a commercially viable LNG tank by putting tanks on the road (used in HDVs) and to demonstrate durability, target production capacity, profitability and fulfil necessary industrial certifications. Cryoshelter have stated that these objectives were achieved, resulting in significant steps forward for LNG tanks for heavy-duty vehicles.

There has been significant research into the production and economics of biomethane. Non-technical barriers still exist around the use of biomethane, and a selection of projects helped to create a wider European biomethane market.

- BIOSURF (2015-2017) worked with 11 partners from seven countries to increase the production and use of biomethane for injection into the natural gas grid and as transport fuel, by removing non-technical barriers to a European biomethane market. This project boosted the volume of cross-border biomethane trade and developed better policy, market support and financial frameworks at the national, regional and local level.
- Bin2Grid (2015-2017) promoted the segregated collection of food waste, its conversion to biogas and then upcycling to produce biomethane. The aim was to bridge the gap between waste management and renewable energy. The project produced a biomethane benchmark tool that provides an indication of economic conditions associated with biogas production, gas upgrading and utilisations of biomethane. The project contributed to discussions on how to achieve a sustainable waste sector at the international, EU and local level.

6.1.4 Implications for future research

The number of European research projects and funding for road transport LNG has contributed to reaching a high TRL. The Cryoshelter project verified the commercial viability of the LNG storage tank, and HDGAS showed that a natural gas engine could achieve a range of 800 km in an HDV. The next steps for LNG for HDVs will address implementing LNG refuelling stations; strategically spread along major transport routes to ensure that LNG fuel is available throughout the journey. For future research, there could be a possibility to replace the LNG/CNG fuels with biomethane, which will further reduce carbon emissions compared to current state-of-the-art natural gas technology. Research is also being done in fuel storage, handling and injection systems, addressing in this way methane leakage. Some recent projects (PEMSFORNANO, DOWNTOTEN and SUREAL 23) suggest NG engines might have higher particle number (PN) emissions than diesel engines; that remains a crucial issue to be addressed if gaseous fuels are introduced as a viable alternative to diesel.

While some projects, such as Bin2Grid, have addressed the utilisation of biomethane produced from waste, more research in the large-scale production is required if this fuel type is to achieve a larger market share as a transport fuel. This is likely to require biomass gasification technologies, which are currently at a lower TRL and therefore could be the focus of future research in biomethane. In the longer-term, it is ideal if biomethane replaces the other methane-based fuels due to its lower overall carbon emissions. Therefore, research into the feasibility of biomethane as an alternative transport fuel is paramount if reduced carbon emissions are to be achieved.

Currently, the main use being considered for methane-based fuels is road transport. However, the use of these fuels in the rail sector is a promising alternative to diesel. One of the areas that has not been explored by the research is using natural gas for rail transport, which has barriers in terms of storage and safety concerns. More research needs to be conducted into the storage and feasibility of the gaseous fuels for locomotives to achieve the higher TRLs. Nonetheless, recently the appearance of Hydrogen powered trains in certain regions in Europe has demonstrated Fuel Cell and Hydrogen technologies as an attractive, zero-carbon alternative to diesel locomotives.

6.1.5 Implications for future policy development

The research and high TRLs of LNG HDVs are helping to deliver the low emission standards required of road transport. Current technology in battery electric vehicles is challenging for HDVs, therefore using LNG as an alternative fuel source shows great promise. LNG engines have been demonstrated to achieve Euro VI standards in the project HDGAS; therefore, making an advance towards improved air quality. The lessons of these projects should be collated and, if it is shown that the technology has been successful in reducing emissions reliably and sustainably, policy could be developed to promote similar applications on a wider basis.

Due to the lack of research into methane-based fuels for other transport modes, it is difficult to assess their potential. Aviation using methane-based fuels is unlikely to be a viable option, due to the safety storage requirements of these fuels. Therefore, future policy could focus on other transport modes for methane-based fuels. The projects NONOX and HERCULES-2 address issues around using methane-based fuels for maritime transport, in particular the use of a dual-fuel engine. If results are positive, European policy could help incentivise further research and eventually widespread uptake of the dual-fuel maritime engine, which would help towards the decarbonisation targets. Annex 1 lists the projects that were reviewed under this sub-theme in preparing the report.

6.2 LPG and bioLPG fuels

This sub-theme assessment contains the research projects relating to liquified petroleum gas (LPG) and bio-liquified petroleum gas (bioLPG) for use as an alternative transport fuel. Conventional petrol cars can be converted relatively cheaply to run on LPG, which can offer quick carbon emission savings. However, users might prefer EV for the long-term, since new AF registrations show it is slightly more prominent than LPG. Policies that limit access to city centres could play an important role in this behaviour.

6.2.1 Overall direction of R&I

Liquefied petroleum gas (LPG) and bio-liquefied petroleum gas (bioLPG) as an alternative fuel source has not received much research attention. There are not many specific LPG projects receiving funding; the majority of projects in this research area also cover the other AF types such as LNG/CNG and other biofuels. The projects that are researching LPG tend to focus on LPG engine components, or components that can be used in either LPG or LNG engines. There is also some attention to the rollout of LPG refuelling stations along core network corridors.

6.2.2 R&I activities

A selection of research projects in this area are shown below. These projects have been selected as they provide examples of innovation in LPG or bioLPG fuels, and are complete with reported results.

- A project investigating the deployment of autogas refuelling stations in different metropolitan areas across Spain and Portugal (CEF Transport: 2015-ES-TM-0030-W, 2016-2018) aimed to increase the available LPG refuelling station infrastructure in Portugal. This consisted of installing 11 LPG refuelling stations along the Atlantic corridor in roads and motorways of Portugal. The objective was to achieve a capacity of 210 vehicles per day, per refuelling station. The refuelling stations are expected to serve both goods and private transport.
- The FUEREX (2011-2012) project aimed to prove the feasibility of a multi-fuel range extender for electric vehicles with high efficiency and ultra-low emissions. The component was designed to be capable of using petrol, LPG, CNG, ethanol and biogas. The project also aimed to integrate these range extenders with state-of-the-art battery packs. The objective was to demonstrate the technology at a realistic scale.
- For converting conventionally fuelled vehicles to run on fuels such as LPG, the fuel injection system must be modified via a conversion kit. InjectoReducer (2016-2017) developed and patented an innovation that reduces costs and emissions, as well as increasing energy efficiency compared to current state-of-the-art. This project aimed to conduct a feasibility study to develop a business plan for InjectoReducer. This project also aimed to facilitate a phase 2 project, which will develop a market-ready prototype product.
- eForFuel (2018-2022) is an ongoing project that will address multiple challenges limiting the success of biofuel technologies. The project intends to produce biofuels from widely available resources, such as water, renewable electricity and industrial CO_2 waste streams, instead of agricultural resources. The products, propane and isobutene, can easily be separated from the microbial culture used to produce them, which reduces production costs and increases energy efficiency. Propane can be used as a component of LPG, and isobutene for production of isooctane.

6.2.3 Achievements

There are several projects improving the current state-of-the-art technology based on European funding for LPG and BioLPG fuels in transport. The results of these projects are shown below.

FUEREX's (2011-2012) range extender for multi-fuel vehicles demonstrated successful bench tests in terms of emissions, efficiency and performance. The range extenders were integrated in three test vehicles (two compact cars and one LGV) with state-of-the-art battery packs. Vehicle testing produced promising results regarding performance and challenging noise, vibrations and harshness (NVH) issues. The team also produced design guidelines explaining range extender optimisation procedures for a given vehicle.

The results from InjectoReducer (2016-2017) reduced the size of the LPG converter prototype, making it easier to install. The project also analysed the supply chain with a view to starting industrial production of InjectoReducer. The resulting reduction in the installation cost of the product may be beneficial to authorities seeking to incentivise car owners to switch to gas (for example, through financial subsidies).

6.2.4 Implications for future research

Due to the limited number of projects researching LPG or bioLPG as an alternative fuel source, it is hard to judge the implications for future research. CEF transport has funded the rollout of LPG refuelling stations in Portugal, which could indicate that there is a future for LPG fuel. Based on the success of this project, future research could address the further market rollout of LPG refuelling stations. Data should be gathered on the type of vehicles using the refuelling stations, to see whether it is passenger cars, LGVs or HDVs using LPG as an alternative fuel source. This will improve the understanding of which type of road transport is using LPGs, if any.

There seems to be promising progress in terms of converting conventionally fuelled petrol engines into engines that can accept LPG and CNG with little installation cost. InjectoReducer reduced the size of an LPG converter, making it easier to install. More funding could be awarded to bring this technology to the market; depending on the success of the refuelling stations in Portugal. If the LPG refuelling stations are not being utilised, then using LPG as an alternative fuel source may not be worth future research.

6.2.5 Implications for future policy development

The use of LPG and bioLPG fuels can assist the decarbonisation of transport. However, there is not much research in this area; therefore, transport may be reliant on other sources of alternative fuels to achieve decarbonisation. The FUEREX project concludes that the main fuel source for passenger vehicles is unlikely to be LPG. LPG is more likely to be used as a range extender in combination with batteries. Future policy for LPG might reflect these results, and focus on other modes of road transport, such as LGVs or HDVs, which require additional power and higher ranges and where battery technology may be insufficient. Annex 1 lists the reviewed projects under this sub-theme.

6.3 Alcohols, ethers and esters fuels

Alcohols, ethers and esters can be produced from renewable sources and offer low-carbon alternatives to conventional fossil fuels in transport. This sub-theme covers a broad range of fuels and projects; which tend to focus on feedstock cultivation or biofuel production, rather than vehicle design. The fuel types researched cover a range of transport modes and feedstocks. A benefit of using alcohol, ethers and esters is the ability for the fuel to be blended with conventional fossil fuel (up to a certain limit, which depends on the fuel type) with minimal changes to the vehicle components.

6.3.1 Overall direction of R&I

There are many projects researching the cultivation of non-food crops for use as feedstocks. Innovative ways to produce biofuels being researched include the production of bioethanol from exhaust gases emitted by the steel industry. Research is being undertaken on business models for biofuels to assist the wide-spread uptake of feedstocks as alternative transport fuels.

Due to the nature of biofuels, they can be used in conventional internal combustion engine (ICE) with minimal required changes; there is a significant research funding for biofuels blended with conventional fossil fuels. This has the added benefit of not requiring any changes to vehicle components, and as little change is required, the projects being researched cover multiple transport modes. To accelerate to use of biofuels commercially there are projects examining biofuel business models and how to make them economically viable.

6.3.2 R&I activities

There is significant funding for alcohol-based fuels projects. Table 11 below shows that there are 26 projects researching alcohol-based alternative fuels, with an average project value of approximately €6 million. Most of these projects focus on bioethanol production, either from new lignocellulosic (dry plant matter) routes or production from residual steel gases. There is some research into biobutanol production and reducing overall fuel cost. These projects are concerned with bioethanol, which can be used as an alternative fuel source in road transport. Most modern passenger vehicles and LGVs can use a blend of bioethanol and gasoline, which explains the high levels of research into road transport.

Few projects focus on ethers/esters as an alternative transport fuel. Typically, fatty acid methyl esters (FAME) are used in road transport; however, there is little research into using FAME for aviation, due to poor performance at low temperatures. Ethers are usually fuel additives rather than a fuel itself, this is due to the low energy density. This results in less research into this fuel type compared to other alcohol-based fuels.

Table 11. Total funding and number of projects for alcohols, ethers and esters research projects.

Fuel type	Total project value (M€)	Total EU contribution (M€)	Number of projects	Average project value (M€)
Alcohol	159.8	119.6	26	6.1
Ester	47.9	20.6	6	8
Ether	10.6	10.3	2	5.3
Other	211.4	131.2	43	4.9
Total	429.6	281.7	77	5.6

A selection of research projects in this area are shown below. These projects have been selected as they are good examples of innovation in alcohol, ether or ester fuels, and are complete with well reported results.

— BECOOL (2017-2021) and MacroFuels (2016-2019) have similar aims to optimally cultivate and crop different feedstocks for biofuel production. The ongoing project BECOOL aims to develop innovative cropping systems, including annual and perennial lignocelluluosic crops, that would increase feedstock availability by at least 50 % without reducing land used for food crops. The MacroFuels project's goals include increasing the biomass supply by developing a rotating crop scheme for the cultivation of seaweed and improving the pre-treatment and storage of seaweed. It will produce biofuels (i.e. ethanol, butanol, furanics and biogas) from seaweed or macro-algae. The project also aims to yield fermentable and convertible sugars at economically relevant concentrations. The project will develop a new system to enhance the production of brown, red and green seaweeds. It will also address the pre-treatment and storage of seaweed at economic scale. Biofuels produced under this project will improve blend limits and will be cheaper to deploy.

— STEELANOL (2015-2018) and FReSMe (2016-2020) are researching the conversion of residual steel gases to bioethanol. STEELANOL's main objective is to demonstrate the cost-effective production of sustainable bioethanol, with the purpose of assessing the value of this bioethanol as an alternative fuel for the transport sector. A demonstration plant will be built - the first of its kind in Europe. FreSMe is a carbon capture and use project that is developing an integrated process to produce methanol from CO_2 and CO recovered from the blast furnace gas of an industrial steelmaking plant, along with hydrogen recovered either from the blast furnace gas or produced by electrolysis. The fuel produced by FreSMe is intended for use in the maritime sector.

— Biodiesel based on fatty acid methyl esters (FAME) is well established for road transport but is not used as an aviation fuel. This is due to the current limitations of the fuel performance in low-temperature conditions. SABRE (2016) has developed and patented a technology for producing biojet fuel from biodiesel obtained from any raw material, including waste cooking oils and fats, through a process bolt on to existing biodiesel production facilities. This process removes the components responsible for the low-temperature poor performance, opening up the potential use of FAME in aviation. The benefit of this is that customers do not have to re-invent the feedstock ecosystem as the technology can be incorporated into existing plants.

— The effects of using biodiesel in combination with fossil diesel is an ongoing area of research. The BIODEG (2008-2011) project aimed to develop knowledge of the consequences of the use of biodiesel in terms of emissions and the effects on motor oil. Different biodiesel sources were investigated. BioRen (2018-2022) is targeting a higher value fuel, glycerol tertiary butyl ether (GTBE), which is a fuel additive to both diesel and gasoline that improves engine performance and cuts harmful exhaust emissions. It can also be blended at higher amounts than ethanol, without having to change the engine. This project aims at developing bio-GTBE, and undertaking engine tests to provide feedback regarding performance, emission results and fuel efficiency.

— ButaNexT (2015-2018) aimed to reduce the cost of the advanced biofuel, bio-butanol. The project produced a prototype of a two-stage pre-treatment and tested a butanol tolerant strain for the fermentation and in-situ recovery of butanol from the fermentation broth. The next stage of the project is to achieve significant impacts in terms of cost reduction, as well as enhanced energy balances and reduced GHG emissions compared to conventional biofuel production.

6.3.3 Achievements

There are several European funded projects improving the current state-of-the-art technology for alcohol, ether or ester fuels in transport. The results of these projects are shown below.

BIODEG (2008-2011) obtained results from advanced modelling on the effects of bio-blended diesel, which showed that toxic nanoparticles are formed in the exhaust pipes of vehicles using these fuels. This represents a mechanism for the increased impacts on human DNA (mutagenicity) from exposure to exhaust gases from bio-blended diesel observed in other studies.

The CLEANTRUCK (2010-2013) project resulted in the purchase of 50 environmental trucks and five cooling units for liquid carbon dioxide (LIC) through 18 private transport companies. These trucks have been used for waste collection, contracting, freight and goods distribution in Stockholm. The project has exceeded the emissions reduction target, and calculations (2010-2014) show that the project has contributed to reducing CO_2 emissions by 3 400 tonnes of CO_2 equivalents. The project also contributed to the world's first public filling station for ethanol ED95 and the first gas-tank station dedicated to heavy traffic.

ButaNexT (2015-2018) developed and demonstrated, at a pilot level, a cost-competitive, efficient and environmentally friendly process to convert sustainable feedstocks into biobutanol. A full environmental, resource, techno-economic and social impact assessment of the entire value chain validated the work. The project also found that, in general, biobutanol as a blend component does not reduce engine efficiency and is beneficial for reducing particulate emissions. The most promising blends were found to be Bu10D (10 % biobutanol, 90 % diesel) and Bu10B10D (10 % biobutanol, 10 % biodiesel and 80 % diesel).

The STEELANOL (2015-2018) project showed that, through a life-cycle assessment, ethanol from residual steel-making gases could save up to 87 % GHG emissions compared to petrol. As of 2019, the first steelanol plant transforming carbon-containing gases from blast furnaces into bioethanol began construction. This will be the first industrial installation of its kind in Europe and is expected to produce 80 million litres of bioethanol each year.

6.3.4 Implications for future research

The project ButaNexT found that the most promising biobutanol blends still consisted of at least 80 % diesel. Further research into this area could improve this, allowing higher blends of biobutanol to be used as a transport fuel. Whether these higher blends of biobutanol require changes to the engine components will need to be considered, as most conventional ICEs can use lower blends.

Currently, multiple varieties of feedstocks are available to produce different types of biofuels. There are issues with biomass feedstocks from food crops, as these can take up space for food production and create various environmental issues when 'carbon sensitive' land is used (e.g. rainforest). Future research should focus on moving away from biomass from crops to lignocellulosic feedstocks or from waste or industrial residues. The results from the project BECOOL will potentially show that innovative lignocellulosic feedstocks can increase feedstock availability by at least 50 % without reducing land used for food crops. Future research into non-crop feedstocks for biomass will further demonstrate the lignocellulosic feedstock benefits.

Research has shown that biobutanol is superior to bioethanol in terms of reduced carbon emissions and higher energy content. It also has the ability to blend with both gasoline and diesel; has a lower risk of separation, corrosion and is resistant to water absorption. Biobutanol should attract more research projects and total funding as it has been shown to be more promising compared to bioethanol. Reducing the cost of producing biobutanol should be the key driver for future research projects, due to high production costs.

6.3.5 Implications for future policy development

In terms of current EU policy regarding decarbonisation of the transport sector, alcohols, esters and ethers offer reductions in carbon emissions relative to fossil fuels. Another benefit of these fuels is that most biofuels can be blended with fossil fuels, up to a certain limit, and be used in conventional fossil fuel engines with little or no modifications required. This results in a reduction of carbon emissions whilst having little capital cost for a vehicle. However, the ButaNext project found that the optimal blend of biofuel to diesel was between 10 % and 20 %. This means that for significant reductions in carbon emissions to be achieved, policy around biofuels blends may not be the answer.

The STEELANOL project shows developments in the area of converting residual gases from waste CO_2 and CO streams into bioethanol, which can offer benefits in terms of waste reduction and carbon emission savings. The project consortium is constructing the first plant of its kind, which uses the residual gases from steel making for bioethanol production. If the whole carbon balance of the project (i.e. considering transport and industry emissions) is better off, then it could prove a strong candidate for future policy considerations.

First-generation biofuels have questionable sustainability aspects in terms of the land-use competition with food crops. Therefore, focusing research on advanced biofuels should be included in future policy development around biofuels, also to address their high production costs including the possibility of additional funding or subsidies. Annex 1 lists the projects reviewed under this sub-theme.

6.4 Synthetic paraffinic fuels

This sub-theme covers the research projects addressing synthetic paraffinic alternative fuels for use in transport. These fuel types are relatively new areas of research, and much of the research is around assessing the commercial viability of these fuels. The most promising use for these fuels are in the aviation sector, as they can provide high energy density. Co-processing is also gaining attention in the fuel production industry.

6.4.1 Overall direction of R&I

Synthetic paraffinic fuels are a new generation of transport fuels made through the Fischer-Tropsch (FT) process from natural gas or biomass, or through hydrotreatment process from vegetable oils or animal fats (HVO). These fuels have the capability of being ‘drop-in’; which means that in theory they can be used in conventional fossil fuel engines up to a blend of 100 %, without the need for a change of engine components or infrastructure. However, 100 % HVO is below the EN590 (diesel) standard for density, and requires a lubricity additive, and has a comparatively much higher cetane number compared to EN590 diesel fuel. Projects in this research area have a large amount of funding for low-carbon aviation fuels (synthetic paraffinic kerosene), as hydrogen and electricity are not seen as viable short-term options for aviation.

The overall R&I direction is towards the production and testing of different synthetic fuels to increase their TRL. There are many different types of synthetic paraffinic fuels. However, it is unclear which are the most economically feasible and reduce the most emissions. Research favours alternative aviation fuels, with some research conducted into heavy-duty road vehicles. Research indicates that this trend will continue into the future, with synthetic paraffinic fuels for the maritime sector receiving little interest.

The use of hydroprocessed esters and fatty acids (HEFA) in the aviation sector is attracting funding research. HEFA can be used as a ‘drop-in’ fuel, and can therefore directly replace jet fuel (kerosene) without requiring any changes to aircraft components. This allows aircraft to reduce carbon emissions simply by switching the fuel. There are also projects researching the conversion of biodiesel to biojet fuel.

6.4.2 R&I activities

There are few projects researching synthetic paraffinic fuels. Research projects that address these fuels are usually high in total value due to the high capital costs of production. Table 12 shows the number of projects and total funding for the different production process HVO, FT and hydrothermal liquefaction (HTL). Most of the projects under SPF are not specific to one fuel type; they tend to cover general research into all alternative fuel types. Most of the research projects consider alternative aviation fuels, which attract higher amounts of funding. The average research funding for HVO fuels projects is over €10 million. The average project researching synthetic paraffinic fuels is €6 million, and total funding in this area is over € 500 million.

Table 12. Total funding and number of research projects researching synthetic paraffinic fuels.

Fuel type	Total project value (M€)	Total EU contribution (M€)	Number of projects	Average project value (M€)
HVO	52.1	19.1	5	10.4
FT	30.3	13.1	6	5
HTL	10.9	10.9	2	5.5
Other/all types	405.3	276.5	71	5.7

Fuel type	Total project value (M€)	Total EU contribution (M€)	Number of projects	Average project value (M€)
Total	498.5	319.7	84	5.9

A selection of research projects in this area is shown below. These projects have been selected as they are good examples of innovation in synthetic paraffinic fuels and are complete with well reported results.

- ALFA-BIRD (2008-2012) gathered a multi-disciplinary consortium with key industrial partners and research organisations to develop the whole chain for clean alternative fuels for aviation. The focus of the project was to address the challenges faced by aviation biofuels in terms of the operational constraints (e.g. flight in cold conditions) and the long lifetime of current aircraft. The project covered a wide range of possible alternative fuels, including paraffinic fuels, HVO, naphthenic fuels as well as representing new production processes such as coal or biomass liquefaction, and oxygenated fuels, such as higher alcohols or furanic compounds. Developing a full-value chain for aviation biofuels is an important research area as the project ITAKA (2012-2015) also researched this area. ITAKA aimed to develop a full-value chain in Europe to produce sustainable synthetic paraffinic kerosene (SPK) at large scale enough to allow testing its use in existing logistic systems and in normal flight operations within Europe. The project assessed sustainability, economic competitiveness and technology readiness of SPK.
- There is research into using HVO for HDVs, due to the potential high energy density of the fuel. COLHD (2017-2020) is an ongoing project that aims to establish an EU market for alternative fuel HDVs. The project has already identified the main challenges to overcome regarding feasibility of alternative fuel HDVs, and the next steps will be to co-develop cross-wise activities involving all key target audiences: raising public awareness, organising workshops with fleet operators and assessing the European Commission on required policy directives.
- TO-SYN-FUEL (2017 – 2021) project aims to demonstrate the conversion of organic waste biomass into biofuels. The project will deploy a new integrated process which combines Thermo-Catalytic Reforming (TCR©) and hydro deoxygenation. It will produce fully equivalent gasoline and diesel substitute (compliant with EN228 and EN590 European Standards) and green hydrogen for use in transport. It will develop at commercial scale a facility to process organic industrial waste into transport biofuels.
- There is significant research funding for the Fischer-Tropsch (FT) process for producing synthetic biofuels. COMSYN (2017-2021) is developing a new biomass-to-liquid production concept that will reduce biofuel production cost by up to 35 %. To date, the first batch of synthetic diesel from the COMSYN project has been demonstrated in a car during a project workshop. Heat-To-Fuel (2017-2021) is another ongoing research project investigating FT technology to produce biofuels. The main objective of Heat-To-Fuel is to deliver competitive prices for biofuel technologies while delivering higher fuel qualities and reduced life-cycle GHG emissions.
- NextGenRoadFuels (2018-2022) is also known as Sustainable Drop-In Transport fuels from Hydrothermal Liquefaction of Low-Value Urban Feedstock. The main objective is to apply advanced hydrothermal liquefaction (HTL), and possible upgrades, to cheap biogenic residues generated in urban activities. This biofuel is expected to achieve similar performance as lignocellulosics. The result will be a low cost (approximately 50-60 Euro cent per litre), sustainable drop-in quality synthetic gasoline and diesel fuels, which at the same time will help reduce GHG emissions by as much as 70 %.
- JETSCREEN (2017-2020) has two particular objectives. First, the development of a platform, which integrates distributed design tools and generic experiments to assess the risks and benefits of SPFs for aviation. Second, to optimise alternative fuels for a maximum energy per kilogram of fuel and a reduction of pollutants emissions. The main innovation lies in the knowledge gained of the detailed composition of SPFs and its potential development in the future.
- Projects SOLAR-JET (2011-2015) and SUN-to-LIQUID (2016-2019) both researched technology to produce sustainable fuel through concentrated sunlight. The SOLAR-JET project demonstrated on a laboratory-scale a process that combines concentrated sunlight with CO_2 captured from air and water to produce kerosene via the Fischer-Tropsch process. This innovative process provides a secure, sustainable and scalable supply of renewable aviation fuel. SUN-to-LIQUID is an ongoing follow-on project (due for completion in December 2019) which aims to advance solar fuel technology to the next field phase. The project is completing an integrated fuel production chain that will be experimentally validated at the pre-commercial scale.

6.4.3 Achievements

There are several projects improving on the current state-of-the-art technology based on European funding for synthetic paraffinic fuels in transport. The results of these projects are shown below.

Although synthetic paraffinic fuel projects are recent, and many of the projects are still on going, there has been significant results and steps-forward for the feasibility and commercialisation of these fuels. ALFA-BIRD tested 12 different alternative jet fuel blends, and identified the four most promising fuels. The project found that these alternative fuel blends for aviation have a positive improvement in environmental impact compared to conventional kerosene. However, the project results stated that successful implementation of these alternative fuels is envisaged only after land-use change assessment related to biomass use and with some efforts from the industrial and political stakeholders.

ITAKA (2012-2015) targeted camelina oil as the best sustainable feedstock that can be produced timely at enough quantity within Europe to produce biojet fuel. The oil is converted into drop-in aviation fuel through the HEFA pathway. The project implemented and harvested large-scale camelina plantations in 2013 and has ongoing plantations. The first batch (in Europe) of HEFA biojet based on camelina oil was produced. This batch of biojet fuel was compliant with the EU RED sustainability requirements, and this fuel was used in the fuel farm and hydrant systems of an airport, allowing flights with biojet blends for several major airlines.

Projects have contributed towards increasing the overall efficiency of producing synthetic paraffinic fuels. The SOLAR-JET project successfully demonstrated the entire production chain for renewable kerosene obtained directly from sunlight, water and CO_2. An achievement of the project was a record solar thermochemical energy conversion efficiency of 1.7 % with the first generation of reactors, this rose even higher to 2.7 % with the second generation. A computational model to describe the behaviour of the solar reactor was also developed and validated with actual experimental data. The success of SOLAR-JET led to a follow-on research project SUN-to-LIQUID.

6.4.4 Implications for future research

There are many ongoing projects in the SPF research area. This suggests that the industry can improve the technology, particularly those technologies with a low TRL such as FT. There is considerable funding and many projects researching the optimal SPF production but few testing the effect on vehicle components. More research should be undertaken in this area to assess the feasibility of using higher blends of SPFs in practice. This is the case for aviation fuels; as the maximum approved blend limit for a kerosene/bio jet fuel blend is 50 %. Further research could address this issue and allow for higher blend limits that would reduce carbon emissions further than current blend limits allow.

In terms of SPF production, the production route from direct sunlight, CO_2 and water offers a sustainable solution to jet fuel. This research seems promising, and, depending on the results of current ongoing projects, further research could be undertaken in this area to increase the TRL and economic feasibility of the fuel. In addition, these fuel types are produced on a small-scale. In order for widespread uptake of these fuels, it is important that the production of SPFs is scaled up to meet the possible future demand from the transport sector.

So far, research has been focused on the aviation sector, with some research into the HDV market. There should be more research into bringing SPF to other transport modes, if economically viable, to explore the potential decarbonisation of each transport mode. Due to the 'drop-in' potential of some SPFs they could be utilised in HDVs with little changes to the vehicle components.

Specific project results (from ALFA-BIRD) stated that for SPFs to be successfully implemented a land-use change assessment related to biomass use and efforts from the industrial and political stakeholders would be needed. This suggests that support should be given to projects specifically researching the land-use change of large-scale biomass use across multiple transport modes.

Hydroprocessed esters and fatty acids (HEFA) is a viable alternative fuel option for the aviation sector, with ITAKA produced biojet fuel compliant with the EU RED sustainability requirements. Further research could be focused on reducing the cost of this fuel type and supporting widespread uptake of HEFA in the aviation sector as a way to phase out kerosene.

6.4.5 Implications for future policy development

SPFs offer potentially large decarbonisation impacts for the aviation and freight sectors where high-energy dense fuels are required. ITAKA produced the first batch of compliant synthetic paraffinic jet fuel, and if the production of these fuels become economically viable, policy could support the widespread uptake in the aviation sector. According to ITAKA, it will help to achieve low-carbon sustainable fuels in aviation at 40 % by 2050. For road freight, the project COLHD is researching using HVO for HDVs. The next steps for this project is to raise awareness between stakeholders around using AFs for road freight. Policy to further raise awareness of using AFs for road freight could help to achieve decarbonisation targets.

Results from the ALFA-BIRD project stated that successful implementation of AF produced from direct sunlight, CO_2 and water is envisaged only after land-use change assessment related to biomass use and with some efforts from the industrial and political stakeholders. Another advantage of such biofuels production is the reduced requirements of land. Policies that consider land use implications of biofuels produced from crops/lignocellulosic biomass might encourage production processes with a lower land footprint such as those using CO_2 as a feedstock. Annex 1 lists the reviewed projects under this sub-theme.

7 Key Performance Indicators

This section analyses the challenges, objectives and actions in the AF roadmap and proposes a set of key performance indicators to assess its implementation. There are two layers of indicators that can be quantified in through statistical figures and the TRIMIS database. The first layer corresponds to the state of the transport sector and to the overview of the use of AFs. The second layer is based on R&I activities funded at European level. Another way to examine the AF roadmap implementation would be to undertake a qualitative rather than quantitative analysis. Section 6 contains a qualitative assessment of the R&I on AFs in Europe, so this section focuses on indicators that can be easily measured.

An analysis of the AF roadmap shows that it contains 51 challenges. Half of them (25) are linked to road-related problems; rail transport has 13 challenges (around 25 % of the total), aviation (7 challenges) and waterborne transport (6 challenges). Table 13 provides detailed information about challenges, transport mode and fuel type.

Table 13. Challenges divided by transport mode and type of fuel

	Road	Rail	Aviation	Waterborne	TOTAL
LNG/CNG	9	4	3	4	20
LPG	1	0	0	0	1
Alcohols, ethers and esters	14	9	0	2	25
SPF	1	0	4	0	5
TOTAL	25	13	7	6	51

A peculiarity of the AF roadmap is that barriers are classified according to transport mode and fuel type, which makes the analysis challenging. In order to overcome these challenges, some interpretation from the authors of this report has been required. Further refinements might be included in future versions of the research, particularly after expert's consultation and workshops updating the AF roadmap.

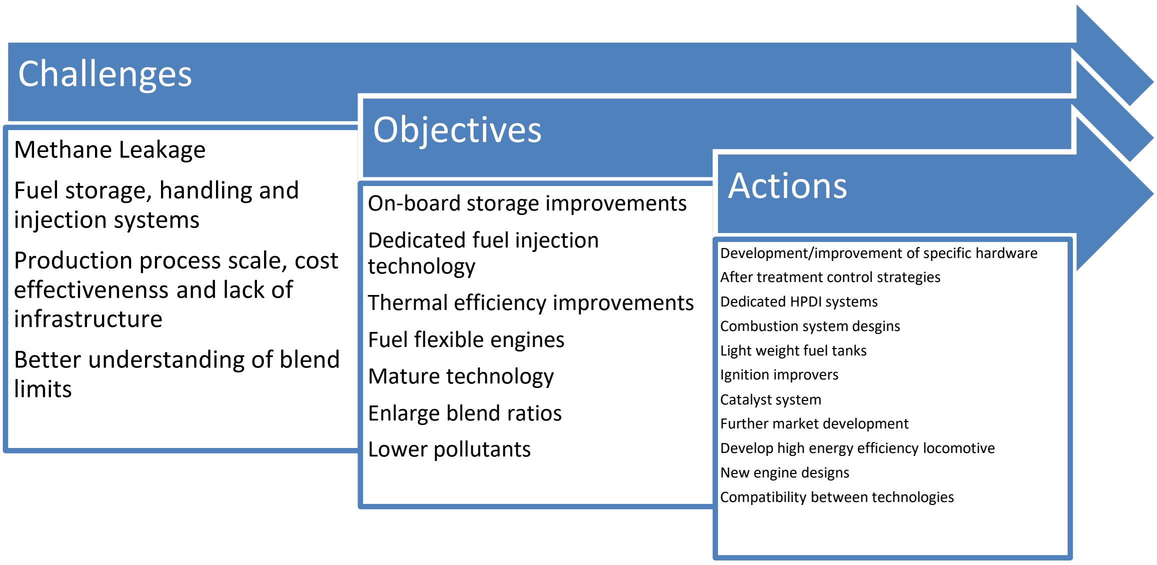
One challenge is that the objectives of the AF roadmap are not clearly defined; therefore, they are obtained following an interpretation of the roadmap. The AF roadmap covers 66 objectives of which 37 are attributed to road transport, 9 objectives are associated with rail transport, 10 objectives are linked to waterborne transport and aviation comprises another 10 objectives. When this distribution is made by fuel type the result is imbalanced. A total of 30 objectives are linked to LNG, 24 are associated with alcohols, ethers and esters (36 % of the total), and the remaining 12 objectives are equally linked to SPF and LPG, with 6 objectives (9 %) each alternative fuel. In conclusion, the objectives of this roadmap are biased in favour of CNG/LNG and alcohols, ethers and esters at the expense of SPF and LPG. Again, further analysis from expert groups will need to explain this (see Table 14).

Table 14. Objective divided by transport mode and type of fuel

	Road	Rail	Aviation	Waterborne	TOTAL
LNG/CNG	14	5	5	6	30
LPG	6	0	0	0	6
Alcohols, ethers and esters	16	4	0	4	24
SPF	1	0	5	0	6
TOTAL	37	9	10	10	

Although the AF roadmap outlined R&I needs, it did not define actions or KPIs. In the context of this roadmap, actions are extracted from the R&I needs which are linked to Challenges and Opportunities (see Annex 2). Some actions overlap with others; therefore, expert opinion should confirm this issue and suggest appropriate actions and associated KPIs. A total of 75 actions were identified in the AF roadmap. The same tendencies that were explained in challenges and objectives appear here; that is, road transport has around 50 % of the actions and there is an uneven distribution favouring LNG and alcohols at the expense of SPF and LPG (see STRIA roadmap of Alternative Energy (2016))[37]. Figure 17 presents a summary of challenges, objectives and actions.

Figure 17. Main challenges, objectives and actions of AFs roadmap.



(37) Available here: https://trimis.ec.europa.eu/stria-roadmaps/low-emission-alternative-energy-transport

The main conclusions derived from the analysis of the AF roadmap are:

— Challenges, objectives and actions (and therefore KPIs) were not clearly defined in the roadmap, the research team had to develop these based on the AF roadmap.

— Not all transport modes have challenges, objectives and actions for all fuel types. The only exception to this rule is road transport where four alternative fuels are present in the existing framework. Moreover, there is a distinction between LDV and HDV in road transport, and for the purpose of the research, they have been merged in this report.

— There is also a distinction between fuel types that make the homogenisation process challenging. Therefore, the statistical analysis must comprise both perspectives: a comparison between transport modes as well as a comparison between types of fuel.

— If the data are analysed from the transport mode perspective, road transport dominates the analysis. Road transport accounts for more users and energy usage than the other transport modes and it is normal that efforts are dedicated to this transport mode. However, the amount of research needed (or actions to be undertaken) within this transport mode is lower than its relative percentage of usage.

— If the data are analysed from the fuel type perspective, CNG/LNG and alcohols dominate the analysis at the expense of SPF and LPG. Therefore, it is worth analysing the other two alternative fuels in the new version of AF roadmap; otherwise, there is the risk of not fully understanding advantages and disadvantages.

Table 15 shows the proposed KPIs by TRIMIS. These KPIs might be useful for monitoring AF roadmap implantation. However, it is also important to note that these KPIs are not fixed and might change in the future.

Table 15. Proposed KPIs for the AF roadmap.

TOPIC	KPI	Unit	Source
Overview of the use of alternative Fuels	Ratio of Alternative Fuel to total fleet	Percentage	European Alternative Fuels Observatory (EAFO)
	Growth of Alternative Fuel vehicles fleet	Percentage	European Alternative Fuels Observatory (EAFO)
	Growth of Alternative Fuel Infrastructure	Percentage	European Alternative Fuels Observatory (EAFO)
Research projects per type of fuel in Europe	Number and budget of research projects allocated to Alternative Fuels	Count/EUR	TRIMIS
Challenges addressed (according to the roadmap)	Number and budget of research projects addressing challenge: methane leakage	Count/EUR	TRIMIS
	Number and budget of research projects addressing challenge: understanding blend limits	Count/EUR	TRIMIS
	Number and budget of research projects addressing challenge: Fuel storage, handling and injection systems	Count/EUR	TRIMIS
	Number and budget of research projects addressing challenge: Production process scale	Count/EUR	TRIMIS

TOPIC	KPI	Unit	Source
	(including the whole chain), cost-effectiveness and lack of infrastructure		
	Number and budget of research projects addressing challenge: Other (e.g. legislative barriers, stakeholder engagement)	Count/EUR	TRIMIS
Road transport	Number and budget of research projects on road transport	Count/EUR	TRIMIS
	Percentage of research projects addressing each challenge (inside road transport)	Percentage	TRIMIS
Rail transport	Number and budget of research projects on rail transport	Count/EUR	TRIMIS
	Percentage of research projects addressing each challenge (inside rail transport)	Percentage	TRIMIS
Aviation	Number and budget of research projects on aviation	Count/EUR	TRIMIS
	Percentage of research projects addressing each challenge (inside aviation)	Percentage	TRIMIS
Waterborne transport	Number and budget of research projects on waterborne transport	Count/EUR	TRIMIS
	Percentage of research projects addressing each challenge (inside waterborne transport)	Percentage	TRIMIS
Multimodal transport	Number and budget of research projects on multimodal transport	Count/EUR	TRIMIS
	Percentage of research projects addressing each challenge (inside multimodal transport)	Percentage	TRIMIS

8 Conclusions and recommendations

This report is based on TRIMIS, and assesses the development and implementation of new technologies in Low-emission alternative energy for transport. Main results from this assessment are:

- Methane based fuels (e.g. CNG, LNG) receive the greatest attention in terms of the number of projects (90) and funding (504 M€). These fuels are in their last development phases with TRLs close to 9. Research in this area is not on the fuel itself but on how to store and handle it, addressing in this way issues related to methane leakage.
- LPG technologies are fully developed. However, they have a limited overall environmental advantage over conventional fuels, since they are equally mostly based on fossil energy sources. There are few research projects (38) and the absence of linked technologies. The low level of R&I might also be explained by the potential electrification of the transport system which would make this AF outdated. Current research focuses on improving car conversion kits and Bio-LPG.
- SPF also benefit from European funding with 498 M€ and 84 projects. The majority of the projects link to the first development phases with TRLs up to 4. In other words, SPF research focuses on biomass production using more sustainable types of biomass. The industry therefore see further improvements with more sustainable production like FT, which is very little or no on the market.
- Alcohols, esters and ethers come in third place of number of projects (77 projects) and funding received (429 M€). Research in this area focuses on biomass production and understanding the blend limits (the so-called blend wall).
- There are not many technologies in the AF roadmap, particularly when compared to other roadmaps. For instance, in this analysis the researchers only identified the top 15 technologies, whereas for other roadmaps there are at least top 20 technologies.
- There are no expectations of relevant or radical changes in the near future. Moreover, registration of electric vehicles (EV) and hybrid electric vehicles (HEV) is growing faster than other alternatively-fuelled vehicles and account together for 60 % of the new registered AF vehicles, with gas vehicles in decline since less than 10 % of new AF cars rely on NG, suggesting users see electricity as a more attractive option. Therefore, changes in the AF market need some time to materialise.
- Bigger MSs tend to invest more and have more projects than smaller MSs, but in normalised terms (e.g. investment per capita); the five most important players are Sweden, Austria, Finland, Belgium and Germany.
- Road transport receives more alternative fuel-related funding than any other transport mode whilst the number of rail projects on alternative fuels on TRIMIS database is rather small. This lies in the electrification of the railway tracks, since all the important ones in Europe are already electrified and in general, only minor lines use diesel. The main advancement in this transport mode might be a shift to electrification or hydrogen rather than run on diesel, always studying its economic feasibility first.

The findings support two crucial policy lessons for the future. First, new technologies and changes in the Alternative Fuels (AF) market need some time to materialise. It means policies should not expect a radical or sudden change, and therefore, transition periods are critical. Second, different fuel types have different development phases. Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG) fuels and related technologies are already available on the market. However, they have a limited overall environmental advantage over conventional fuels, since they are equally mostly based on fossil energy sources and might have issues related to pollutant emissions and leakage, which make the overall environmental benefit of such fuels questionable. First-generation of Synthetic Paraffinic Fuels (SPF) and alcohols, esters and ethers are already available across Europe, but these have questionable sustainability aspects in terms of the land-use competition with food crops. Current research focuses on more sustainable generation of SPF and alcohols, esters and ethers, which will require more extended periods to be on the market. Moreover, they have environmental advantages over CNG, LNG and LPG and therefore focusing future research on advanced biofuels should be included into any future policy development around biofuels. From a policy point of view, CNG, LNG and LPG offer possible short – and medium-term solutions if the associated emission and leakage issues are overcome, however the electrification of transport might be a more beneficial and attractive solution to long-term decarbonisation. Improved and more sustainable version of SPF and alcohols, esters and ethers might also provide a long-term solution. Nevertheless, all policies should ensure clean and decarbonised transport and consider broader social, environmental and economic impacts.

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List of abbreviations and definitions

AF	Alternative Fuel
AT	Austria
BE	Belgium
BG	Bulgaria
CEF	Connecting Europe Facility Framework Programme
CH	Switzerland
CNG	Compressed Natural Gas
CY	Cyprus
CZ	Czech Republic
DE	Germany
DG MOVE	Directorate-General for Mobility and Transport
DG RTD	Directorate-General for Research and Innovation
DK	Denmark
EC	European Commission
EE	Estonia
EEA	European Environmental Agency
EL	Greece
ES	Spain
EU	European Union
EV	Electric vehicles
FAME	Fatty acid methyl esters
FI	Finland
FP7	7th Framework Programme
FR	France
FT	Fischer-Tropsch
GTL	Gas to Liquid
H2020	Horizon 2020 Framework Programme
HDV	Heavy-duty vehicles
HEFA	Hydroprocessed esters and fatty acids
HEV	Hybrid electric vehicles
HR	Croatia
HTL	Hydrothermal liquefaction
HU	Hungary
HVO	Hydrotreated Vegetable Oil
IE	Ireland
IMO	International Maritime Organisation
IT	Italy
JRC	Joint Research Centre

LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LT	Lithuania
LU	Luxembourg
LV	Latvia
MS	Member State
MT	Malta
NETT	New and emerging transport technologies and trends
NL	The Netherlands
PL	Poland
PN	Particle number
PT	Portugal
R&I	Research and Innovation
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
SPF	Synthetic Paraffinic Fuels
STRIA	Strategic Transport Research and Innovation Agenda
TEN-T	Trans-European Transport Network
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology readiness levels
UK	United Kingdom

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Annexes

Annex 1. Project Table

The following table shows all projects that were considered during the development of this report and the sub-theme(s) under which they were considered.

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
N/A	Breakthrough LNG deployment in Inland Waterway Transport	2016-2018	CEF - Connecting Europe Facility	Y			
N/A	Connect2LNG	2015-2018	CEF - Connecting Europe Facility	Y			
N/A	Deployment of autogas refuelling stations in different metropolitan areas between Spain and Portugal	2016-2018	CEF - Transport		Y		
N/A	LNG for shipping and logistics in Europe	2016-2018	CEF - Connecting Europe Facility	Y			
N/A	Methanol: A Future Transport Fuel based on Hydrogen and Carbon Dioxide?	2012-2014	N/A			Y	
N/A	PAN-LNG-4-DANUBE	2016-2019	CEF - Connecting Europe Facility	Y			
N/A	Study and deployment of integrated gas & water cleaning system and biofuel-MGO blend for the upgrade of the Atlantic corridor	2015-2017	CEF - Connecting Europe Facility			Y	
N/A	Watertruck+	2014-2019	CEF - Connecting Europe Facility	Y			
2016-MT-SA-0005	Technical Study and Cost-Benefit Analysis for the Development of LNG as a Marine Fuel in Malta	2017-2019	CEF - Connecting Europe Facility	Y			

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
2016-PL-SA-0011	The small-scale LNG Reloading Terminal in Gdansk and bunkering services	2017-2019	CEF - Connecting Europe Facility	Y			
2NDVEGOIL	Demonstration of 2ND generation VEGetable OIL fuels in advanced engines	2008-2011	FP7-ENERGY			Y	
ACEP	Airlander Civil Exploitation Project	2015-2017	H2020-EU.3.4	Y			
ADVANCEFUEL	Facilitating market roll-out of RESfuels in the transport sector to 2030 and beyond	2017-2020	H2020-EU.3.3	Y	Y	Y	Y
AGFOODTRADE	New Issues in Agricultural, Food and Bioenergy Trade	2008-2011	FP7-KBBE			Y	Y
ALFA-BIRD	Alternative Fuels and Biofuels for Aircraft Development	2008-2012	FP7-TRANSPORT				Y
ALTER-MOTIVE	Deriving effective least-cost policy strategies for ALTERnative autoMOTIVE concepts and alternative fuels	2008-2011	IEE - Intelligent Energy Europe	Y	Y	Y	Y
AQUASONIC-diesel	UPSCALE OF ELECTRICAL PULSES TECHNOLOGY CAPABLE OF FRAGMENTING HYDROCARBON CHAINS IN FUEL FOR MARITIME APPLICATIONS	2015-2015	H2020-EU.3.4	Y			
ARCHIMEDES	Achieving Real Change with Innovative Transport Measures Demonstrating Energy Savings	2008-2012	FP7-TRANSPORT	Y	Y	Y	Y
ASSIST	Assessing the social and economic impacts of past and future sustainable transport policy in Europe	2011-2013	FP7-TRANSPORT	Y	Y	Y	Y
AUTOREVAL	Automotive Residue Valorization	2016-2016	H2020-EU.3.4				Y

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
Baltic Biogas Bus	Baltic Biogas Bus: Increase the use of biogas buses in public transport to reduce the emissions in urban areas in the Baltic Sea Region	2009-2012	INTERREG-IVB	Y			Y
BATTERIE	Better Accessible Transport to Encourage Robust Intermodal Enterprise	2012-2014	INTERREG-IVB	Y	Y	Y	Y
BattleCO2	Biomass incorporation in AsphalT manufacturing Towards Less Emissions of CO_2	2015-2018	LIFE				Y
BEAUTY	Bio-ethanol Engine for Advanced Urban Transport by Light Commercial Vehicle & Heavy Duty (BEAUTY)	2009-2011	FP7-TRANSPORT			Y	
BECOOL	Brazil-EU Cooperation for Development of Advanced Lignocellulosic Biofuels	2017-2021	H2020-EU.3.3			Y	
Bin2Grid	Turning unexploited food waste into biomethane supplied through local filling stations network	2015-2017	H2020-EU.3.3	Y			
BIO4A	Advanced sustainable BIOfuels for Aviation	2018-2022	H2020-EU.3.3			Y	
BIODEG	Influence of bio-components content in fuel on emission of diesel engines and engine oil deterioration	2008-2011	N/A			Y	
BIOLCA LIFE11 ENV/ES/000585	Demonstration of a Tool for the Evaluation and Improvement of the Sustainability in the Transport Sector	2012-2014	LIFE	Y	Y	Y	Y
BioRen	Development of competitive, next generation biofuels from municipal solid waste	2018-2022	Horizon 2020			Y	
BIOSIRE	Biofuels and Electric Propulsion Creating Sustainable Transport in Tourism Resorts	2008-2011	IEE - Intelligent Energy Europe			Y	Y

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BIOSURF	BIOmethane as SUstainable and Renewable Fuel	2015-2017	H2020-EU.3.3	Y			
BIOTRETH	Influence of bioethanol fuels treatment for operational performance, ecological properties and GHG emissions of spark ignition engine	2013-2015	Polish-Norwegian Research Programme			Y	
BLUESKY	Robust kit to convert diesel vehicles to Natural Gas and Biogas for extended life and reduced contaminants emission	2018-2018	H2020-EU.3.4	Y			
ButaNexT	Next Generation Bio-butanol	2015-2018	H2020-EU.3.3			Y	
CAPRICE	Capital regions integrating collective transport for increased energy efficiency	2008-2011	INTERREG-IV	Y	Y	Y	Y
CARGOMAP	Air Cargo Technology Road Map	2011-2013	FP7-TRANSPORT				Y
CATCH_MR	Cooperative approaches to transport challenges in Metropolitan Regions	2010-2012	INTERREG-IV	Y	Y	Y	Y
CATS	City Alternative Transport System	2012-2013	FP7-TRANSPORT	Y	Y	Y	Y
CESAR	Cryogenic Electronics for Space Applications and Research	2010-2014	FP7-SPACE	Y	Y	Y	Y
CHATT	Cryogenic Hypersonic Advanced Tank Technologies	2012-2015	FP7-TRANSPORT				Y
CITYLAB	City Logistics in Living Laboratories	2015-2018	H2020-EU.3.4	Y	Y	Y	Y

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
CIVITAS CAPITAL	CIVITAS CAPITAL making the best of CIVITAS!	2013-2016	FP7-TRANSPORT	Y	Y	Y	Y
CIVITAS DYN@MO	CIVITAS DYN@MO	2012-2016	FP7-TRANSPORT	Y			
CIVITAS ECCENTRIC	Innovative solutions for sustainable mobility of people in suburban city districts and emission free freight logistics in urban centres.	2016-2020	H2020-EU.3.4	Y	Y	Y	Y
CIVITAS ELAN	Mobilising citizens for vital cities Ljubljana - Gent - Zagreb - Brno - Porto	2008-2012	FP7-SST	Y	Y	Y	Y
CLEAN DRIVE	Clean Drive - A campaign for Cleaner Vehicles in Europe	2010-2013	IEE - Intelligent Energy Europe	Y	Y	Y	Y
CLEANPORT	Alternative Fuels and Solutions for Port's Cold-Ironing: Standardisation of Regulatory Framework and Demonstration of Feasible Exploitation	2014-2017	CEF - Connecting Europe Facility	Y			
CLEANTRUCK LIFE08 ENV/S/000269	CLEAN and energy efficient TRUCKs for urban goods distribution	2010-2013	LIFE	Y		Y	
CO2-NeuTrAlp	CO2-Neutral Transport for the Alpine Space (CO2-NeuTrAlp)	2008-2011	INTERREG-IVB	Y	Y	Y	Y
COLHD	Commercial vehicles using Optimised Liquid biofuels and HVO Drivetrains	2017-2020	H2020-EU.3.4	Y			Y
COMSYN	Compact Gasification and Synthesis process for Transport Fuels	2017-2021	H2020-EU.3.3				Y

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
CONVERGE	CarbON Valorisation in Energy-efficient Green fuels	2018-2022	H2020-EU.3.3			Y	
CORE	CO2 REduction for long distance transport	2012-2015	FP7-TRANSPORT	Y			
CORE-JETFUEL	Coordinating research and innovation of jet and other sustainable aviation fuel	2013-2016	FP7-TRANSPORT				Y
CoRePaSoL	Characterisation of Advanced Cold-Recycled Bitumen Stabilised Pavement Solutions	2013-2014	ERA-NET - European Research Area Net				Y
Cryoshelter	Bringing a new LNG-tank technology to industrial readiness	2015-2017	H2020-EU.3.4	Y			
CS2-WP714-DE	Advanced Design of Very High Power Density Piston Engine and Thermal Management Challenges for Aircraft Application	2016-2018	H2020-EU.3.4				Y
DEFENDER	DEsign, development, manufacture, testing and Flight qualification of nExt geNeration fuel storage system with aDvanced intEgRated gauging and self-sealing capabilities	2017-2021	H2020-EU.3.4				Y
DiGas Dual fuel	A novel dual fuel system for diesel locomotive modernisation to CNG or LNG operation	2016-2017	H2020-EU.3.4	Y			
DTEU	Decarbonising Transport in Europe	2018-2022	H2020-EU.3.4	Y	Y	Y	Y
E6 Evolution	Dual Fuel Euro6 Engine Conversion Feasibility Study	2015-2016	H2020-EU.3.4	Y	Y	Y	Y

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
EARN	Effects on Availability of Road Network	2013-2014	ERA-NET - European Research Area Net				Y
ECO2	Sub-seabed CO2 Storage: Impact on Marine Ecosystems (ECO2)	2011-2015	FP7-Environment	Y			
ECOSTARS	ECO Stars Europe	2011-2014	IEE - Intelligent Energy Europe	Y	Y	Y	Y
EEECSM-2	Energy and Environmentally Efficient Cooling System for Maritime use	2016-2018	H2020-EU.3.4	Y		Y	
EINSTAIN	Engine INSTallation And INtegration	2016-2018	H2020-EU.3.4				Y
ENCLOSE	ENergy efficiency in City LOgistics Services for small and mid-sized European Historic Towns	2012-2015	IEE - Intelligent Energy Europe	Y			
FlexiFuel-SOFC	Development of a new and highly efficient micro-scale CHP system based on fuel-flexible gasification and a SOFC	2015-2019	H2020-EU.3.3				Y
FlexJET	Sustainable Jet Fuel from Flexible Waste Biomass	2018-2022	H2020-EU.3.3				Y
FLYwheel	Low-cost, High-efficiency FLYwheel Energy Recovery System for On-highway Commercial Vehicles	2017-2017	H2020-EU.3.4	Y	Y	Y	Y
FReSMe	From residual steel gasses to methanol	2016-2020	H2020-EU.3.3			Y	

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
FUEL DEOX	Optimisation of an on-board adsorbent/catalyst unit for aviation fuel thermal stability improvement	2016-2018	H2020-EU.3.4				Y
FUEREX	Multi-fuel Range Extender with High Efficiency and ultra low Emissions	2011-2012	FP7-TRANSPORT	Y			
FUEREX	Multi-fuel Range Extender with High Efficiency and ultra-low Emissions	2011-2012	FP7-TRANSPORT		Y	Y	
GasOn	Gas-Only internal combustion engines	2015-2018	H2020-EU.3.4	Y			
GASTONE	New powertrain concept based on the integration of energy recovery, storage and re-use system with engine system and control strategies	2013-2017	FP7-TRANSPORT	Y			
GASVESSEL	Compressed Natural Gas Transport System	2017-2021	H2020-EU.3.4	Y			
Go4Synergy in LNG	Go4Synergy in LNG	2016-2019	CEF - Connecting Europe Facility	Y			
GRAIN	GReener Aeronautics International Networking	2010-2012	FP7-TRANSPORT				Y
GRAIN 2	GReener Aeronautics International Networking-2	2013-2015	FP7-TRANSPORT				Y
GREEN EFFORTS	Green and Effective Operations at Terminals and in Ports	2012-2014	FP7-TRANSPORT	Y			
GreenDrive	A molecular fuel modifier for ships able to reduce the costs related to fuel and maintenance for fleet operators	2016-2016	H2020-EU.3.4	Y		Y	

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
GrowSmarter	GrowSmarter	2015-2019	Horizon 2020				Y
GT WHR system	Green Turbine WHR System	2015-2015	H2020-EU.3.4	Y			
Gybrid	EKUPD	2016-2016	H2020-EU.3.4	Y			
HARMLES	Dry lubricated Harmonic Drives for space applications	2011-2015	FP7-SPACE	Y	Y	Y	Y
HDGAS	Heavy Duty Gas Engines integrated into Vehicles	2015-2018	H2020-EU.3.4	Y			
Heat-To-Fuel	Biorefinery combining HTL and FT to convert wet and solid organic, industrial wastes into 2nd generation biofuels with highest efficiency	2017-2021	H2020-EU.3.3				Y
HELIOS	The Development of a New Ship Engine Generation	2010-2013	FP7-TRANSPORT	Y			
HERCULES-2	Fuel Flexible, Near-Zero Emissions, Adaptive Performance Marine Engine	2015-2018	H2020-EU.3.4	Y		Y	Y
HISP	High Performance Solid Propellants for In-Space Propulsion	2011-2014	FP7-SPACE	Y	Y	Y	Y
HVDCGEN	High Speed HVDC Generator / Motor	2017-2022	H2020-EU.3.4				Y
HyMethShip	Hydrogen-Methanol Ship propulsion system using on-board pre-combustion carbon capture	2018-2021	H2020-EU.3.4			Y	

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
I4F	Instant Foam for Fighting Forest Fires	2016-2018	H2020-EU.3.4			Y	Y
I-Fusion	Innovative FUel Sensor for engIne OptimisatioN	2014-2015	H2020-EU.3.4	Y	Y	Y	Y
IMPERIUM	IMplementation of Powertrain Control for Economic and Clean Real driving emIssion and fuel ConsUMption	2016-2019	H2020-EU.3.4	Y	Y	Y	Y
INGAS	Integrated Gas Powertrain - Low Emission, CO2 Optimised and Efficient CNG Engines for Passenger Cars (PC) and light duty vehicles (LDV)	2008-2012	FP7-TRANSPORT	Y			
InjectoReducer	Integrated reducer-filter-injector unit for natural gas engines	2016-2017	H2020-EU.3.4	Y	Y		
INNOSUTRA	Innovation Processes in Surface Transport (INNOSUTRA)	2010-2011	FP7-TRANSPORT	Y	Y	Y	Y
INOMANS²HIP	INOvative Energy MANagement System for Cargo SHIP	2011-2014	FP7-TRANSPORT	Y		Y	Y
ITAKA	Initiative Towards sustAinable Kerosene for Aviation	2012-2015	FP7-AAT				Y
JETSCREEN	JET Fuel SCREENing and Optimization	2017-2020	H2020-EU.3.4				Y
JOULES	Joint Operation for Ultra Low Emission Shipping	2013-2017	FP7-TRANSPORT	Y		Y	Y
KEROGREEN	Production of Sustainable aircraft grade Kerosene from water and air powered by Renewable Electricity, through the	2017-2022	H2020-EU.3.3				Y

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
	splitting of CO_2, syngas formation and Fischer-Tropsch synthesis						
LaMiLo	Last Mile Logistics - Sustainable City logistics	2011-2015	INTERREG-IVB	Y	Y	Y	Y
LeanShips	Low Energy And Near to zero emissions Ships	2015-2019	H2020-EU.3.4	Y		Y	Y
LEMCOTEC	Low Emissions Core-Engine Technologies	2011-2015	FP7-TRANSPORT				Y
LNG Blue Corridors	LNG Blue Corridors	2013-2017	FP7-SST	Y			
MacroFuels	Developing the next generation Macro-Algae based biofuels for transportation via advanced bio-refinery processes	2016-2019	Horizon 2020	Y		Y	
MAGDRIVE	Magnetic-Superconductor Cryogenic Non-contact Harmonic Drive	2011-2014	FP7-SPACE	Y	Y	Y	Y
MARITIMECO2 LIFE08 ENV/CY/000461	Impact assessment for the adoption of CO_2 emission trading for maritime transport	2010-2012	LIFE	Y		Y	Y
MDC	CNG Fuels- Mother and Daughter CNG Station Concept	2016-2016	H2020-EU.3.4	Y			
MHyBus LIFE07 ENV/IT/000434	Methane and Hydrogen blend for public city transport bus: technical demonstrative application and strategic policy measures	2009-2011	LIFE	Y			
MICRO B3	Marine Microbial Biodiversity, Bioinformatics and Biotechnology	2012-2015	FP7-KBBE			Y	

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
More BalticBiogasBus	Investing and testing more biogas buses in the Baltic Sea Region, based on studies within the previous Baltic Biogas Bus project	2013-2014	INTERREG-IVB	Y			Y
NANOL4TP	Decreasing fuel consumption in transport	2018-2018	H2020-EU.3.4			Y	Y
NEWS	Development of a Next generation European Inland Waterway Ship and logistics system	2013-2015	FP7-SST	Y			
NextGenRoadFuels	Sustainable Drop-In Transport fuels from Hydrothermal Liquefaction of Low Value Urban Feedstocks	2018-2022	Horizon 2020				Y
NGV - PRA	Affordable Personal Refuelling Appliance (PRA) for Natural Gas Vehicles using oil-free coaxial compression	2015-2016	H2020-EU.3.4	Y			
NOWASTE	Engine Waste Heat Recovery and Re-Use	2011-2015	FP7-TRANSPORT		Y	Y	Y
NYSMART	Novel dual-fuel system for modernisation of air-polluting diesel locomotives to clean and efficient gas operation	2017-2019	H2020-EU.3.4	Y			
p-DRIVE	Pyrolysis of Derived Residues of waste, providing Improved gas for Vehicle Engines	2015-2016	H2020-EU.3.4	Y			
Photofuel	Biocatalytic solar fuels for sustainable mobility in Europe	2015-2019	H2020-EU.3.3			Y	
POLYWOOD LIFE10 ENV/AT/000112	Polygeneration of Fuels, Heat and Electricity from Wood	2011-2015	LIFE	Y			

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
Pro-Klima Autoklimaanlage LIFE09 INF/DE/000012	Information campaign Pro-Klima: Efficient car climatisation through natural cooling substances	2010-2013	LIFE		Y	Y	
Pro-Klima Autoklimaanlage LIFE09 INF/DE/000012	Information campaignPro-Klima: Efficient car climatisation through natural cooling substances	2010-2013	LIFE	Y			Y
Prominent	Promoting Innovation in the Inland Waterways Transport Sector	2015-2018	H2020-EU.3.4	Y		Y	Y
Pulp and Fuel	Pulp and Paper Industry Wastes to Fuel	2018-2022	H2020-EU.3.3				Y
REDIFUEL	Robust and Efficient processes and technologies for Drop In renewable FUELs for road transport	2018-2021	H2020-EU.3.3			Y	
REWOFUEL	REsidual soft WOod conversion to high characteristics drop-in bioFUELs	2018-2021	H2020-EU.3.3	Y		Y	
RotorDEMO	Norsepower Rotor Sail Solution demonstration project	2017-2018	H2020-EU.3.4			Y	Y
RVCR	KGYAT have developed the RVCR, the world's first commercially viable Rotary Variable Compression Ratio (VCR) engine.	2016-2016	H2020-EU.3.4				Y
SABRE	Transforming the biodiesel industry to meet Europe's need for sustainable aviation fuel: business feasibility study, technical validation and real-world demonstration	2016-2016	H2020-EU.3.4			Y	
SOLAR-JET	Solar chemical reactor demonstration and Optimisation for Long-term Availability of Renewable JET fuel	2011-2015	FP7-TRANSPORT				Y

Project acronym	Project name	Project duration	Source of funding	Methane fuels	LPG/BioLPG	Alcohols, Ethers & Esters	Synthetic Paraffinic Fuels
SPARTAN	SPAce exploration Research for Throatable Adavanced eNgine	2011-2014	FP7-SPACE	Y	Y	Y	Y
STARGATE	Sensors Towards Advanced Monitoring and Control of Gas Turbine Engines	2012-2015	FP7-TRANSPORT				Y
STEELANOL	Production of sustainable, advanced bio-ethANOL through an innovative gas-fermentation process using exhaust gases emitted in the STEEL industry	2015-2018	H2020-EU.3.3			Y	
SUN-to-LIQUID	Integrated solar-thermochemical synthesis of liquid hydrocarbon fuels	2016-2019	H2020-EU.3.3				Y
TEFLES	Technologies and Scenarios For Low Emissions Shipping	2011-2014	FP7-TRANSPORT	Y		Y	Y
Throttle free natural gas engine	High performance throttle free gas engines for inland vessels	2014-2016	Horizon 2020	Y			
TORC	Truck with an Organic Rankine Cycle	2016-2018	H2020-EU.3.4	Y	Y	Y	Y
TO-SYN-FUEL	The Demonstration of Waste Biomass to Synthetic Fuels and Green Hydrogen	2017-2021	H2020-EU.3.3				Y
TRAVEL PLAN PLUS	Travel Reduction Attainment Via Energy-efficient Localities PLANning	2008-2011	IEE - Intelligent Energy Europe	Y	Y	Y	Y
WASTE2ROAD	Biofuels from WASTE TO ROAD transport	2018-2022	H2020-EU.3.3				Y

Source: Own elaboration.

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