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ADVANCEFUEL

Market analysis

D5.1 RESfuels in transport sector

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ADVANCEFUEL at a glance

ADVANCEFUEL (www.ADVANCEFUEL.eu) aims to facilitate the commercialisation of renewable transport fuels by providing market stakeholders with new knowledge, tools, standards and recommendations to help remove barriers to their uptake. The project will look into liquid advanced biofuels – defined as liquid fuels produced from lignocellulosic feedstocks from agriculture, forestry and waste – and liquid renewable alternative fuels produced from renewable hydrogen and CO_2 streams.

In order to support commercial development of these fuels, the project will firstly develop a framework to monitor the current status, and future perspectives, of renewable fuels in Europe in order to better understand how to overcome barriers to their market roll-out. Following this, it will investigate individual barriers and advance new solutions for overcoming them.

The project will examine the challenges of biomass availability for second-generation biofuels, looking at non-food crops and residues, and how to improve supply chains from providers to converters. New and innovative conversion technologies will also be explored in order to see how they can be integrated into energy infrastructure.

Sustainability is a major concern for renewable fuels and ADVANCEFUEL will look at socio-economic and environmental sustainability across the entire value chain, providing sustainability criteria and policy-recommendations for ensuring that renewable fuels are truly sustainable fuels. A decision support tools will be created for policy-makers to enable a full value chain assessment of renewable fuels, as well as useful scenarios and sensitivity analysis on the future of these fuels.

Stakeholders will be addressed throughout the project to involve them in a dialogue on the future of renewable fuels and receive feedback on ADVANCEFUEL developments to ensure applicability to the end audience, validate results and ensure successful transfer and uptake of the project results. In this way, ADVANCEFUEL will contribute to the development of new transport fuel value chains that can contribute to the achievement of the EU's renewable energy targets, and reduce carbon emissions in the transport sector to 2030 and beyond.

To stay up to date with ADVANCEFUEL's stakeholder activities, sign up at:
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Executive Summary

The transport sector is the only major EU sector where Green House Gas (GHG) emissions are continuously increasing. In 2017, transport emissions, excluding international aviation and maritime, represented close to 22% of the total emissions and were 20% higher than in emissions in 1990. While road transport has contributed the most to the transport sector's GHG emissions, the largest increase in final energy consumption has occurred in the aviation sector between 1990 and 2016, and this sector is expected to continue to grow rapidly. International shipping activity is also expected to increase in the near future which is driven by increasing globalisation and trade.

In response to increasing emissions, the EU has set several targets to mitigate and limit GHG emissions from transport. An overall target of a 60% reduction in GHG emission within the transport sector by 2050 was set in 2011 (compared to 1990). However, the 2015 Paris Agreement aspires to limit global warming to less than 1.5ºC. A study conducted for the European Parliament suggests that by 2050 global aviation emissions should be at least 41% lower than in 2005, and the global emissions of the shipping sector to be at least 63% lower.

Switching to renewable and carbon-neutral fuels is one of the key options to reduce GHG emissions. Advanced biofuels are among the few options available to utilise in the short-medium term, particularly for the aviation and shipping sectors. Other RESfuels from non-biological origin can gain traction in the medium to long term in regard to achieving the desired climate mitigation. Both advanced biofuels (based on lignocellulosic feedstocks) and renewable fuels from non-biological origin are referred to as RESfuels throughout the remainder of this report.

The deployment of renewable fuels within the transport sector has been mainly driven by national and EU policies. The future of RESfuels is also highly dependent on a secure and stable policy framework. Since 2009, a mandatory target for renewable energy in road and rail transport within the EU was implemented. As opposed to road and rail transport sectors, aviation and shipping sectors are regulated at an international level. As of 2021, a global market-based measure, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), will be operational. This is in order to address CO_2 emissions in the aviation sector. Compliance will be voluntary until 2027. After this term, the provisions of the measure will be considered mandatory. The target is to reduce GHG emissions by 50% by 2050, as compared to 2005. Until recently, in the shipping sector, the focus has been on minimising the air polluting emissions (SO_x, NO_x, PM). In spring 2018 the IMO adopted a strategy to reduce total GHG emissions from shipping by 50% in 2050, and to reduce the average carbon intensity by 40% in 2030 and 70% in 2050, compared to 2008.

RESfuels based on lignocellulosic feedstocks are not yet produced at a commercial scale. The production costs of these fuels are more than twice the price of conventional fossil fuels in the road transport sector. The production costs of more refined biofuels (biokerosene) are even higher while kerosene prices are roughly the same as diesel prices. The shipping sector can on the one hand use a large range of advanced biofuels. On the other hand, the prices of marine fuels (notably heavy fuel oil) are even lower than diesel prices.

A number of scenarios conducted for the European Commission as well as IEA studies indicate that large quantities of RESfuel will be needed by 2050 in order to meet the Paris Agreement goals. These scenarios consider all available renewable options and include energy efficiency gains and additional energy saving. If the 2050 biofuel demand is to be met solely from advanced biofuels, a more than 10-18 fold increase in their supply and adoption will be needed within the time frame of 2017 to 2050. More specifically, the 2050 projections that focus on the Paris Agreement Goals are as follows:

- Liquid biofuel demand from all transport modes, excluding international shipping, is projected to be in the range of 1200-1800 PJ. For the aviation sector biofuel demand appears to be in the range of 580-960 PJ. For liquid e-fuels the demand projection range is 220-850 PJ. Liquid e-fuels refer to liquid fuels produced from hydrogen and CO2, provided that the hydrogen is generated from renewable resources, i.e. by using renewable power for the electrolysis of water to gain hydrogen for further processes.
- The international shipping demands another 930-1300 PJ liquid biofuels. Liquid e-fuels (both liquid and gashouse) demand projection is 350 PJ in one of the scenarios.

In conclusion, biofuels and e-fuels are among the important options needed to decarbonise the transport system in Europe. Their future market deployment is thus crucial. In addition to renewable fuels, it is crucial to maximise energy efficiency and energy saving. 2050 scenarios indicate significant fuel consumption reductions. The scenarios that focus on the achievement of the Paris Agreement indicate a need for energy reduction of more than 40% in 2050 compared to 2015.

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Contents

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1. Introduction

1.1. Background

The transport sector is the only major EU sector where Green House Gas (GHG) emissions are still increasing. In 2017, transport emissions (excluding international aviation and maritime) accounted for close to 22% of the total emissions and were 20% higher than in 1990. Transport emissions, including international aviation and maritime transport emissions, were close to 26% of total emissions (EC, 2018). Passenger cars have contributed the most to the sector's GHG emissions since 1990. This was followed by heavy-duty vehicles (HDVs), which includes heavy goods vehicles (HGVs) and buses.

Within the EU28, emissions from aviation accounted for around 13% of the total transport GHG emissions and around 3.3% of the total EU CO_2 emissions (EEA, 2017). The sector is expected to continue to grow rapidly in the coming decades, with a predicted annual growth in emissions from the European aviation sector of between 1% and 4% (EASA et al., 2016). The GHG emissions in regard to international shipping have also been increasing, making the sector the second highest increase of emissions of any sector, exceeded only by international aviation. The total CO_2 emissions from international shipping are roughly 2.5% of the global total (EC, 2016) and shipping activity is expected to increase in the future, driven by increasing globalisation and trade.

In the framework of fighting climate change, the EU has set several targets on limiting greenhouse gas emissions from the transport sector. The European Commission's 2011 Transport White Paper sets out a target of 60% reduction in transport GHG emissions by 2050 compared to 1990. It is necessary to highlight that these targets were set within the context of limiting global warming to 2ºC, whereas the Paris Agreement established a more exact target of 1.5ºC. Thus, much more effort will be needed in order to meet the 1,5°C objective of the Paris Agreement.

The research conducted for the European Parliament suggests that global aviation emissions in 2030 should not be more than 39% higher than in 2005, while in 2050 they should be at least 41% lower than in 2005 to meet the Paris Agreement goals. Global emissions of the shipping sector in 2030 should be 13% lower than in 2005. In 2050 they should be 63% lower than in 2005. If the additional non-CO_2,[1] climate change-relevant emissions are taken into consideration, these reductions would need to be even higher (EP, 2015).

A switch to renewable and carbon-neutral fuels is one of the options to reduce GHG emissions and decarbonising the transport sector. Biofuels are among the few options available in the short term, particularly for aviation and shipping sectors. Other RESfuels from non-biological origin can gain importance in the medium to long term in achieving climate change mitigation.

[1] Non- CO_2 emissions, in general, refer to methane (CH_4), nitrous oxide (N_2O) and the so-called F-gases.

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1.2. Objectives of the study

This study focuses on the market outlook of RESfuels within the transport sector. RESfuels in the ADVANCEFUEL project refer to "liquid advanced biofuels" and "other liquid renewable fuels". Liquid advanced biofuels are all liquid biofuels produced from lignocellulosic biomass. The project scope is limited to lignocellulosic biomass thereby covering most of the feed-stocks listed in Annex IX of the EU renewable energy directive (DIRECTIVE (EU) 2018/2001) (hereafter referred to as the REDII). Other liquid renewable fuels are essentially all renewable fuels that do not have biomass as feedstock basis. These include liquid fuels produced from hydrogen and CO_2, provided that the hydrogen is generated from renewable resources, i.e. by using renewable power for the electrolysis of water to gain hydrogen for further processes. They will be referred to as e-fuels throughout the remainder of the report.

The main aim of this study is to define the order of magnitude by which the market uptake of RESfuels could grow for the time frames 2030 and 2050. As RESFuels have been and will need policy support, this report looks at not only to the historical trends and the cost competitive-ness of RESFuels but also at policies and regulations defining the demand for RESfuels. De-mand analysis for RESfuels for 2030 and 2050 have been based on the three different publica-tions. Two of them are from the European Commission, where different scenarios have been quantified with the PRIMES energy systems model. The other one is the World Energy Out-look (WEO) 2018 projections from International Energy Agency (IEA).

This report is one of the building blocks of the integrated analysis that will be conducted through modelling within WP6 of the ADVANCEFUEL project.

1.3. Report outline

This report is structured as follows. First the policy context is introduced (chapter 2). This chapter introduces the most relevant and recent policy developments of RESfuel use within the transport sector. This is followed by the chapter where historical trends concerning energy consumption and the type of fuel mix for the sectors road transport, aviation and maritime are presented. In this chapter also the current use of biofuels is presented. Chapter 4 is dedi-cated to the production costs of RESfuels in comparison to the fossil fuel comparators. This chapter also introduces the most viable advanced biofuel options for the aviation and mari-time sectors and highlights the recent developments that have occurred. Chapter 5 provides an overview of the future projections derived from the scenarios developed for the European Commission (PRIMES) and IEA. Finally, Chapter 6 draws the overall conclusions based on the previous chapter analysis.

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2. Policy context

The European Union (EU) began implementing biofuel-related targets in 2003 with Directive 2003/30/EC. This Directive set indicative biofuel penetration targets of 2% by the end of 2005 and 5.75% by the end of 2010. In 2009, the EU Commission passed two major directives supporting the increased use of renewable fuels extending to 2020. The Renewable Energy Directive (RED) (Directive 2009/28/EC) mandates that 20% of all energy usage in the EU, including at least 10% of all energy in road transport fuels, be produced from renewable sources by 2020. Alongside the RED, an amended Fuel Quality Directive (FQD) (Directive 2009/30/EC) was passed requiring that, by 2020, the road transport fuel mix in the EU should be 6% less carbon intensive than a fossil diesel and gasoline baseline. This was followed by the ILUC Directive (EU/2015/1513) limiting the use of food-based biofuels to 7%.

More recently, the revised Renewable Energy Directive (EU) 2018/2001 establishes a binding EU target of at least 32% for 2030 with a review for increasing this figure in 2023. It also introduces an EU incorporation obligation to fuel suppliers in Europe. The main elements of this directive relevant to the transport sector are presented in Table 1 and illustrated in Figure 1.

Table 1. RED II targets and caps, as specified in Article 25

Overall RES mandate in transport	Renewable fuels (consumed in all transport modes and RE-E in road and rail transport[2]) share in road and rail transport to reach 14% by 2030 (energy based). If a Member State caps crop-based biofuels at a level lower than 7%, then it can reduce the overall 14% target.	
Sub-mandate regarding advanced biofuels	Biofuels from Annex IX A type feedstock	0.2% required in 2022 1.0% required in 2025 3.5% required in 2030 Fuels may be double-counted to achieve this target, which de facto implies that the targets are only 0.1%, 0.5% and 1.75%
Capped biofuels	Biofuels from Annex IX B type feedstock(mainly used cooking oil and animal fats)	Limited to 1.7%[3] of transport fuels. these fuels may be double counted to arrive at a contribution of 3.4%
	Crop-based biofuels	Capped at 1% above the 2020 fraction per Member State, or 7% (whichever is lower) if the 2020 fraction is below 1%, the crop cap may be set at 2% maximally. If a Member State caps crop-based biofuels at a level lower than 7%, then it can reduce the overall 14% target.

2 Recycled carbon fuels can be taken into account. This option is left to MS.
3 For Malta and Cyprus this 1.7% cap is not applicable.

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High ILUC risk biofuels	Definition will be given by European Commission in delegated act.	High ILUC risk biofuels will be phased out towards 2030 unless they are certified as being low ILUC risk
Other forms of renewable energy in transport	No sub-targets are specified, but they contribute to achieve the overall 14% (or lower) target	
	Renewable electricity	When used in road vehicles, counts 4 times. When used in rail, counts 1.5 times
	Renewable liquid and gaseous transport fuels of non-biological origin.	(can be produced from renewable electricity).
Shipping and aviation	Biofuel use in aviation and maritime can be counted 1.2 times	

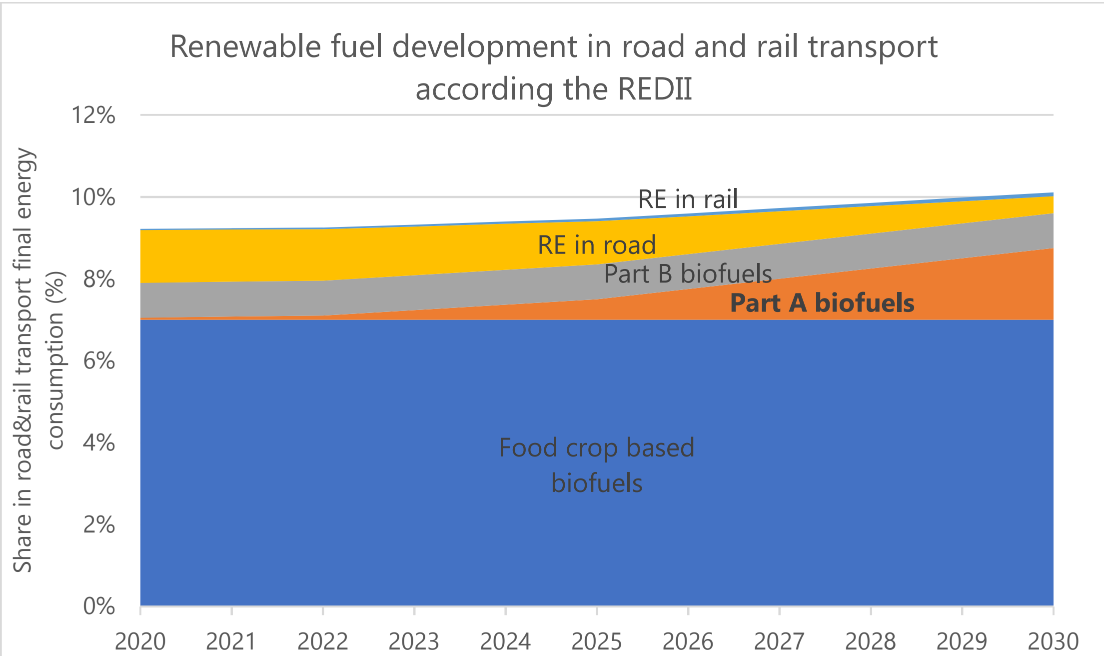

Figure 1. Illustration of RES fuels in transport according to REDII (multiple counting included)

Note: current use of conventional food crop based biofuels is much less than 7%.

In addition to above policies, the Transport White Paper (EC, 2011b) set out two targets to the transport sector: a 20% GHG emission reduction from 2008 levels by 2030 and a 60% reduction from 1990 levels by 2050. While this target has its origin in regard to limiting the global warming to no more than 2ºC above pre-industrial levels a more ambitious target was adopted through the Paris Agreement. The Paris Agreement refers to a 1.5ºC target, which has implications for all sectors, including transport (Hoen et al., 2017).

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2.1. Aviation sector

Since 2012 the EU emission trading system (EU ETS) has included in the CO_2 emissions from aviation. All airlines operating in Europe are required to monitor, report and verify their emissions and they need to surrender allowances against those emissions. The scope of the EU ETS was limited to flights within the European economic Area (EEA) until 2016 to support the development of a global measure by the International Civil Aviation Organisation (ICAO).

In 2016, ICAO agreed on a resolution for a global market-based measure to address CO_2 emissions from the international aviation as of 2021. The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) aims to stabilize CO_2 emissions at 2020 levels. Airlines will be required to:

- monitor emissions on all international routes
- offset emissions from routes included in the scheme by purchasing eligible emission units generated by projects that reduce emissions in other sectors (e.g. renewable energy).

The first two phases of CORSIA (pilot and first phase) will run from 2021 to 2027 and will be voluntary. It will become mandatory from 2027. The initiative builds on initial work carried out by the international aviation sector to reduce net aviation CO_2 emissions by 50% by 2050, from a 2005 baseline (ACI et al., 2010). The concrete actions taken by the aviation sector to curb the GHG emission are:

- in March 2017, ICAO agreed to adopt a new CO_2 standard for aircraft emissions to improve aircraft fuel efficiency[4].
- the European Advanced Biofuels Flightpath (EABF) was developed and set a goal of producing 2 million tonnes of sustainable biofuel for civil aviation by 2020 (EC, 2011a).

There are various on-going initiatives at the European level aimed at increasing the market penetration of bio-based aviation fuels. However, despite these initiatives, the current consumption in Europe is very low when compared to the potential production capacity. Only Germany reported the use of bio-based aviation fuels as part of the official 2016 figures under the framework of the Emissions Trading Directive (EASA, 2019).

The aviation and marine sectors are not included in the mandatory fuel volumes in the REDII, but fuels supplied to the aviation and shipping industry will receive a multiplier of 1.2 (i.e. 1 GJ of fuel counts for 1.2 GJ of fuel towards the mandated targets, on an energy content basis) according to the REDII.

Recently, Norway has announced a blending obligation to the aviation sector. On October 4, 2018 the country's Ministry of Climate and Environment announced it will require aviation fuel to contain at least 0.5% advanced biofuel starting in 2020. According to information released by the ministry, the mandate will require those who sell aviation fuel in Norway to ensure that 0.5% of the fuel comes from advanced biofuels, defined as those made from waste and residues. Biofuels made from "problematic raw materials," such as palm oil, will not qualify to meet the mandate. The government goal has announced that 30% of the airline fuels will be sustainable by 2030[5].

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4 This standard will apply to new aircraft type designs from 2020 onwards, and to aircraft type designs already in production as of 2023. Production of those aircraft that do not meet the standard by 2028 will no longer be permitted, unless their designs are sufficiently modified (ICAO, 2017).

5 https://www.regjeringen.no/no/aktuelt/biodrivstoff-i-luftfarten/id2613122/

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2.2. Shipping sector

Shipping is regulated at the international level by the International Maritime Organisation (IMO), a specialized body of the United Nations. The focus has been on minimising the air polluting emissions. GHG emissions are currently not regulated, but expectations are that regulation of CO_2 emissions will be implemented in the short to medium term (Hsieh & Felby, 2017). The IMO has increased mandatory requirements to monitor GHG emissions from international shipping in this regards[6]. In spring 2018 the IMO adopted a strategy to reduce total GHG emissions from shipping by 50% in 2050, and to reduce the average carbon intensity by 40% in 2030 and 70% in 2050, compared to 2008.

In 1973, the International Convention for the Prevention of Pollution of Ships (MARPOL) was signed with an aim to minimise pollutions from ships in the oceans and seas as well as the air emissions. In 2005, a new annex (Annex IV) was introduced to regulate the air pollution, including Nitrogen Oxide (NO_x), Sulphur Oxide (SO_x), Volatile Organic Compounds (VOC) and Particular Matters (PM). Fuel quality related requirement were also established and emission control areas (ECA) were created. In ECA jurisdictions strict SO_x, NO_x and PM emission targets have been set. Table 2 introduces the sulphur content standards based on the IMO agreement.

These regulations mean that an estimated 70% of the fuels currently used by the sector needs to be modified or changed. There are different ways to reduce SO_x emissions. One solution is to use liquefied natural gas (LNG) as fuel. This requires the retrofitting of the engines. Another solution can be using low sulphur fuels, which will require more refining in the refineries. Methanol can also be used with the latest diesel engine technologies but the supply infrastructure is mentioned to be premature(ref).

Biofuels with very low sulphur levels are technical viable options to reduce SO_x emissions. Section 4.2 introduces the suitable RESfuels options to this sector.

Table 2. Sulphur emission standards inside and outside ECAs based on IMO agreements (IEA, 2017)

Sulphur content of fuel permitted in ECAS	
Before 1 July 2010	1.5% m/m
Between 1 July 2010-1 January 2015	1% m/m
After 1 January 2015	0.1% m/m
Sulphur content of fuel permitted outside ECAs	
Before 1 January 2012	4.5% m/m
Between 1 January 2012-1 January 2020	3.5% m/m
After 1 January 2020	0.5%m/m

*m/m refers to percentage mass of sulphur dioxide gases in the total mass of the emission.

6 New requirements covers ships with 5,000 GT and above to collect fuel consumption data for each type of fuel they use, as these ships account for approximately 86% of the CO_2 emissions from international shipping (IMO,2016).

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3. Transport sector energy consumption -historical trends

In the EU28, road transport accounts for the largest amount of transport energy consumption (including international shipping), accounting for 73% of total demand in 2014. Figure 2 illustrates the EU28 final energy consumption in road and rail transport per energy carrier between the years 1990-2017. The main observations are as follows.

- Final energy consumption in road and rail transport has increased between 1990 and 2007. Thereafter, the economic recession caused a subsequent decline in transport demand between 2007 and 2015 in road transport. Nevertheless, between 1990 and 2015, there was a 27% net growth in the energy consumption of road transport in the EU28.
- The share of diesel fuel sales has increased over the years, from a share of total sales in 2001 of 55.6% to a share of 71.8% in 2016. This reflects to a large degree the increasing dieselisation of Europe's vehicle fleet during that period. Diesel fuel consumption is significant in most of the 28 EU Member States (> 60% of total fuel sales) with the exception of Cyprus, Greece, Malta and the Netherlands (EC, 2018). Tax incentives and structural trends in transport have been the main reason for the shift from gasoline to diesel in Europe. The Dieselgate[7] scandal in 2015 has resulted in several countries announcing plans to end sales of new diesel and gasoline cars (e.g. the UK and France by 2040).

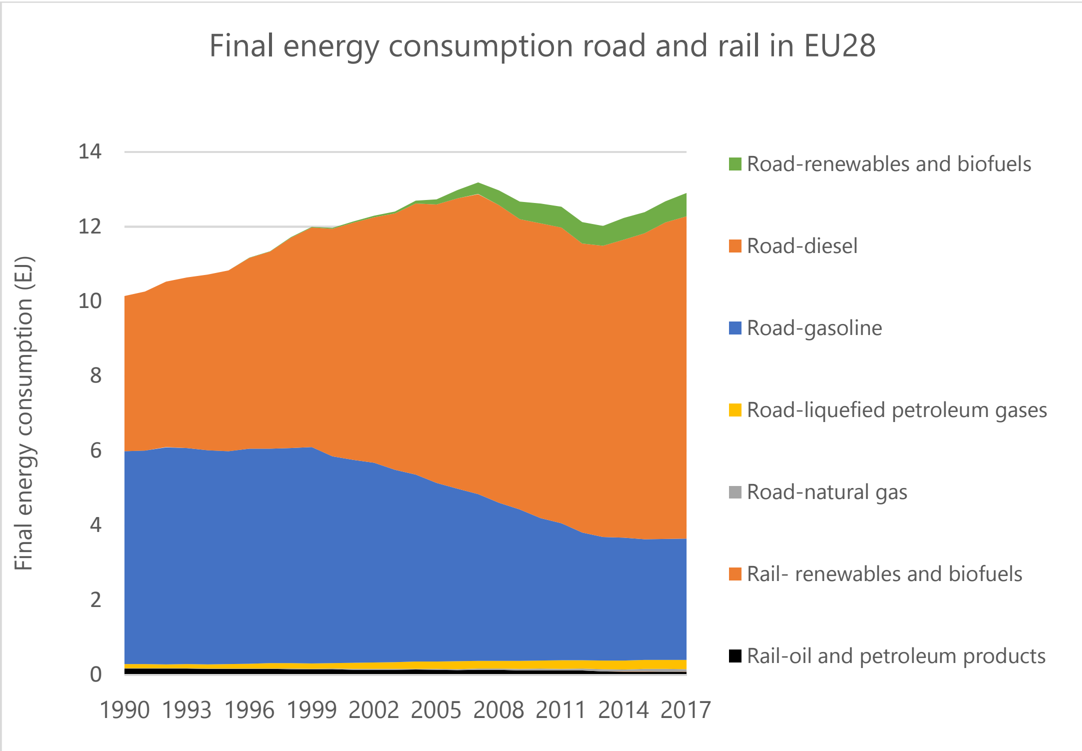

Figure 2. Transport energy consumption road and rail transport in the EU28 (Eurostat, 2019)

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[7] Volkswagen (VW) installed defeat devices in its cars to circumvent emission standards.

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The shipping sector saw the greatest decline in energy consumption during the economic recession; it dropped between 2008 and 2009, with a total decrease of 20% between 2007 and 2017 (see Figure 3). Increase in final energy consumption between 1990 and 2076 was 17% in shipping sector. While the domestic shipping has decreased, the international marine bunkers has experienced an increasing trend between 1990 and 2017. Type of oils used in the shipping sector was dependent mainly on the market price of the residual fuel oil and shipping oil.

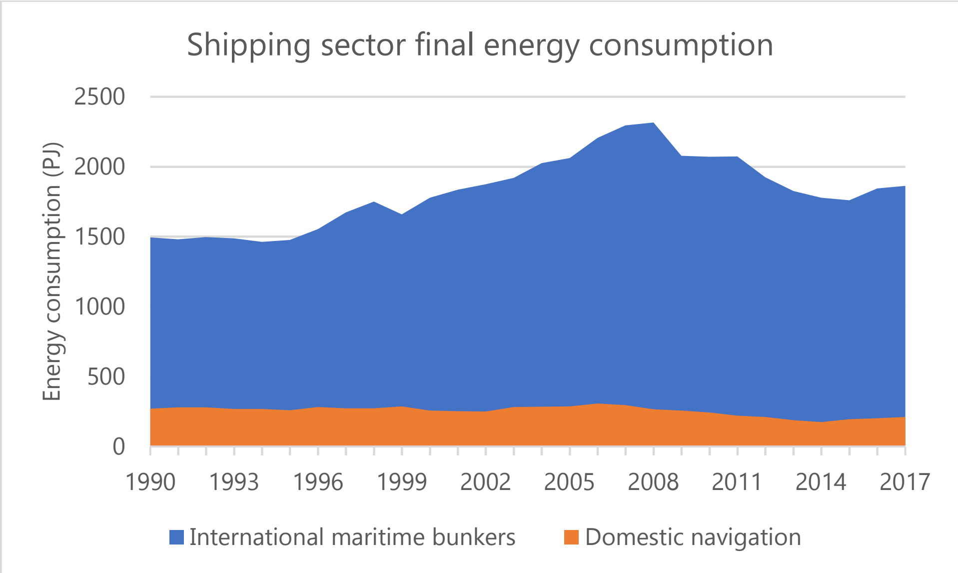

Figure 3. EU 28 final energy consumption international maritime bunkers and domestic shipping (Eurostat, 2019)

Air transport final energy consumption increased by more than 90% between 1990 and 2017. While domestic aviation energy demand has been stable, this increase was experienced in the international aviation. The main fuel used in aviation is jet fuel (Jet A-1, also called kerosene) used in civil aviation. In addition a kerosene-gasoline mixture (Jet B, also called JP-4)[8] is used for military jets (Oil tanking, 2019).

8 This special blend (grade Jet B, also called JP-4) of about 65% gasoline and 35% kerosene is used in regions with particularly low temperatures, because it is more flammable with a flash point of 20°C, and its freezing point can be as low as -72°C (as compared to -47°C for Jet A-1). However, the engines must be suitable for the use of these aviation fuels (Oil tanking, 2019)

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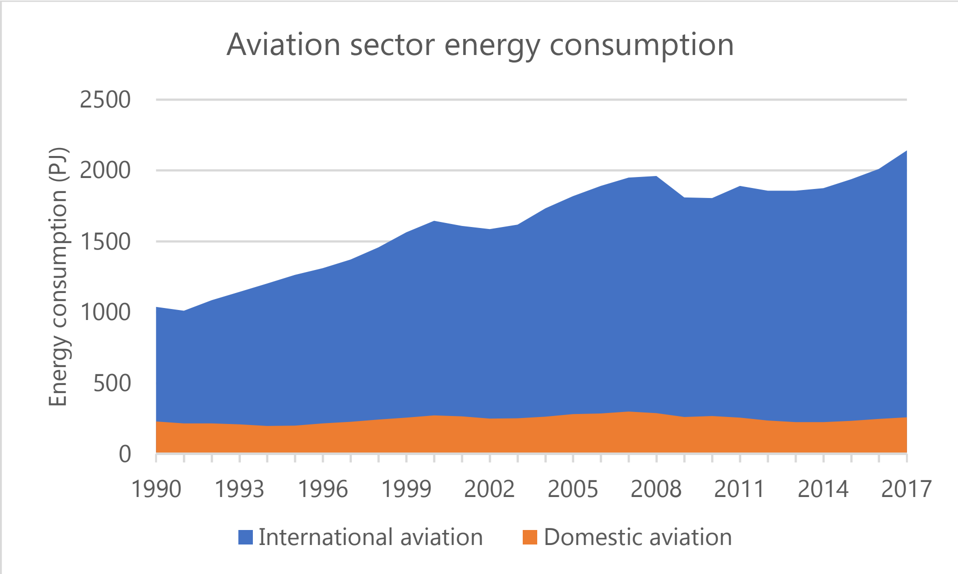

Figure 4. EU 28 final energy consumption aviation (Eurostat, 2019)

3.1. Current use of biofuels

Biofuels have been predominately used in road transport. In 2018, total biofuels blending with fossil fuels is forecasted at 5.2% (energy basis, exclusive of double-counting, see graph below); 3.6% for bioethanol and 5.8% for biodiesel and HVO. Blending of conventional (food based) biofuels is estimated at 4.1%, well below the 7% cap set by the ILUC Directive, and for 2021-2030 by the RED II (See Figure 5).

Blending of advanced (non-food based) biofuels is estimated at 1.2%. The majority of these advanced biofuels blended (~1.0%) is produced from waste fats and oils (listed in Part B of Annex IX of the RED), and only a small percentage is produced from agricultural and forestry by-products such as pine oil and cellulosic feedstocks oils (listed in Part A of the REDII Annex IX).

Biofuel use in the aviation sector is limited to demonstration flights, mainly based on HEFA bio jet (Hydro processed Esters and Fatty Acids), using oleochemical feedstocks such as oil and fats. This is the foundation technology, which was ASTM certified in 2011 (Use in only 50% blends for commercial aviation). Many major airlines and air forces have been involved in some kind of test flights with biofuels (ETIP,2018).

In the shipping sector as well, uptake of biofuels is extremely limited. Less than 1% of the current fuel supply makes use of biofuel, with the few initiatives currently operational mostly involving inland or short-sea shipping[9].

[9] https://www.ship-technology.com/features/backing-biofuels-will-shipping-industry-ever-get-board/

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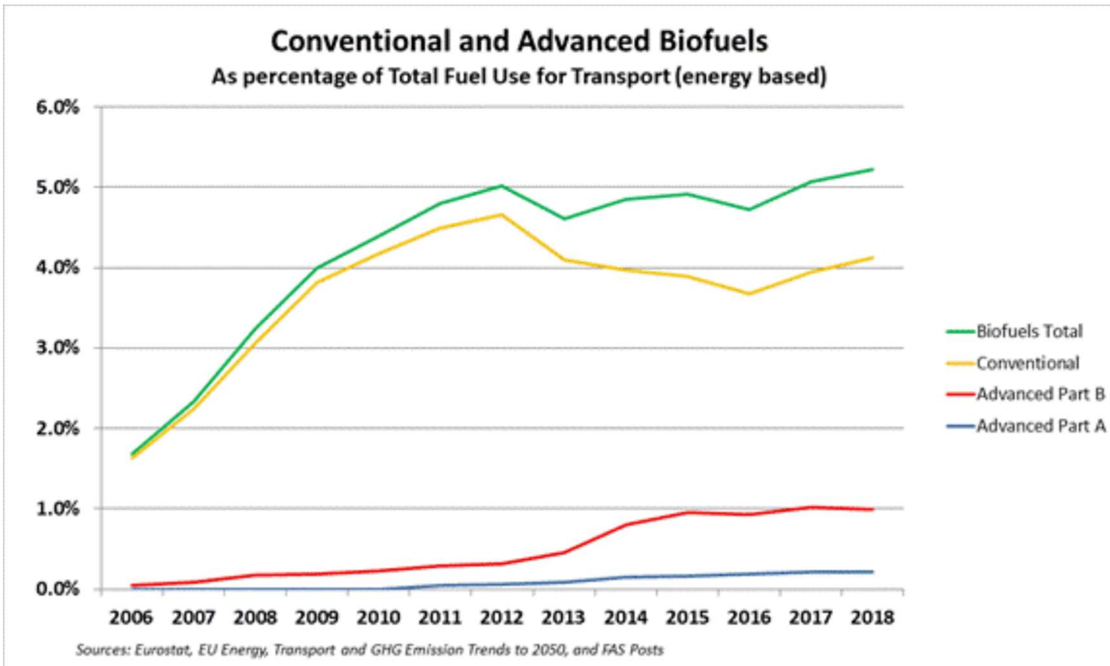

Figure 5. Biofuel deployment in Europe as share of total fuel used for transport in Europe (USDA, 2018)

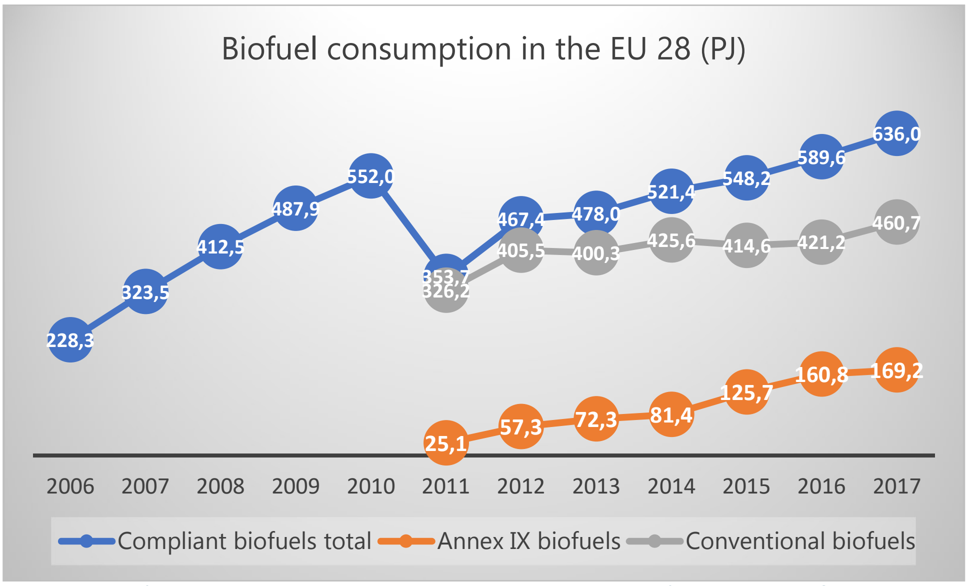

Figure 6. Biofuel consumption between 2006 – 2017 (Derived from Eurostat Shares, 2019)

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4. RESfuel production costs and their use in aviation and shipping

The production cost of advanced biofuels are currently higher than for fossil fuels. The lowest production cost of advanced biofuels is even 50-100% higher than their crude oil based alternatives. That is why their existence depends on policy support. Figure 7 illustrates the advanced biofuel production costs in comparison to the historic crude oil prices. Biomethane via biogas (anaerobic digestion) can be competitive to fossil fuels in certain niche markets.

RESfuels from non-biological origin in this project refers to electrolysis of renewable electricity to hydrogen followed by the conversion with CO_2 via catalysis to liquid fuels. There are a limited number of large scale demonstration projects in Iceland (Carbon Recycling International) and in Germany (Innogy). The fuel production costs are stated to be above 100 €/GJ when renewable electricity is assumed to cost 5 €cent/kWh. Cost increases to around 150 €/GJ when the electricity cost is assumed as 11 €cent/kWh (LBST & Dena, 2017) decreasing to 80 €/GJ by 2050 with an electricity price of 8€cent/kWh(E4Tech, 2018).

In the future, the possible increases in crude oil price and the cost reductions in advanced biofuel technologies and e-fuels will be the two crucial determinants of cost competitiveness of RESfuels. Next to these, the costs of infrastructure and vehicle adoption (depending on the RESFuel type) are important aspects for their market roll out.

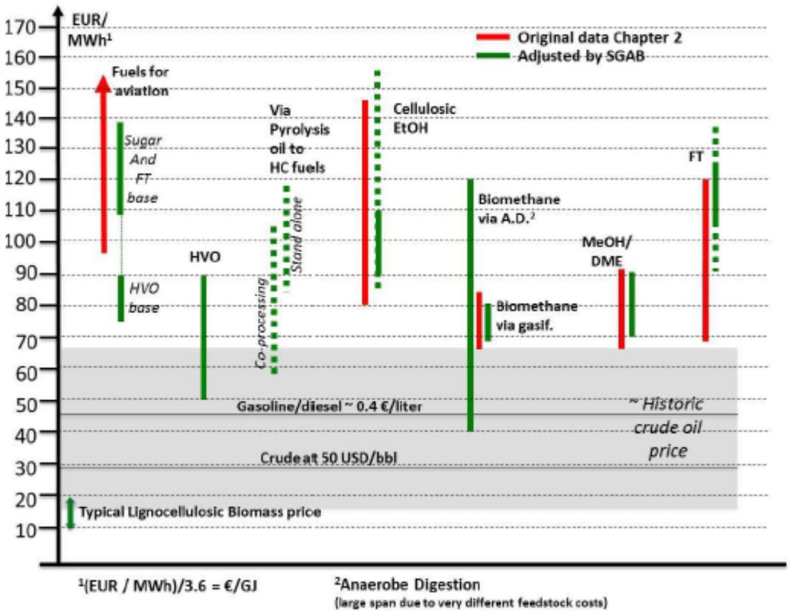

Figure 7. Summary of advanced biofuels production cost (SGAB, 2017)

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4.1. Aviation

Biofuel use in aviation (referred to as sustainable aviation fuel-SAF) consists of test flights and their current penetration in the global aviation market can be considered zero. The properties and the conditions for the fuels to be used in aviation are defined by ASTM standards. There are five biofuel production routes recognised by ASTM standards (see Table 3).

HEFA has been the predominant fuel for test flights and more extended tests. None of the HVO plants that were in operation before 2016 produce a dedicated stream of bio-jet. They are all mainly focusing on renewable diesel. The Altair plant in California, USA, came on stream in 2016, with the production capacity of 100,000 ton per year. This is the first plant that produces a combination of a dedicated stream of HEFA bio-jet and HVO biodiesel (SGAB, 2017).

One of the main reasons for the low uptake and the related absence of large-scale production capacity is the price gap between sustainable aviation fuels and conventional jet fuel. The competitive nature of aviation sector and the pressure to compete on ticket pricing limits the willingness to invest in "green" initiatives. Fuel costs are the most important operation costs of the airlines (fuel costs are approx. 1/3 of the average airline operation costs (Klauber et al., 2017).

The cost difference relative to fossil-based jet fuel differs significantly across regions, driven by feedstock price, conversion technology/capital investment, etc. The price of kerosene in spite of further refining requirements to meet the quality demand, does not significantly deviate from the price of diesel for road transport. Figure 8 illustrates the price comparison of jet fuel with diesel. As a consequence, there is no preference to produce aviation biofuels rather than drop in HVO diesel or some other advanced biofuels. Besides, in most cases aviation fuels causes a minor overall loss in the yield of liquid products relative to producing road transport fuels.

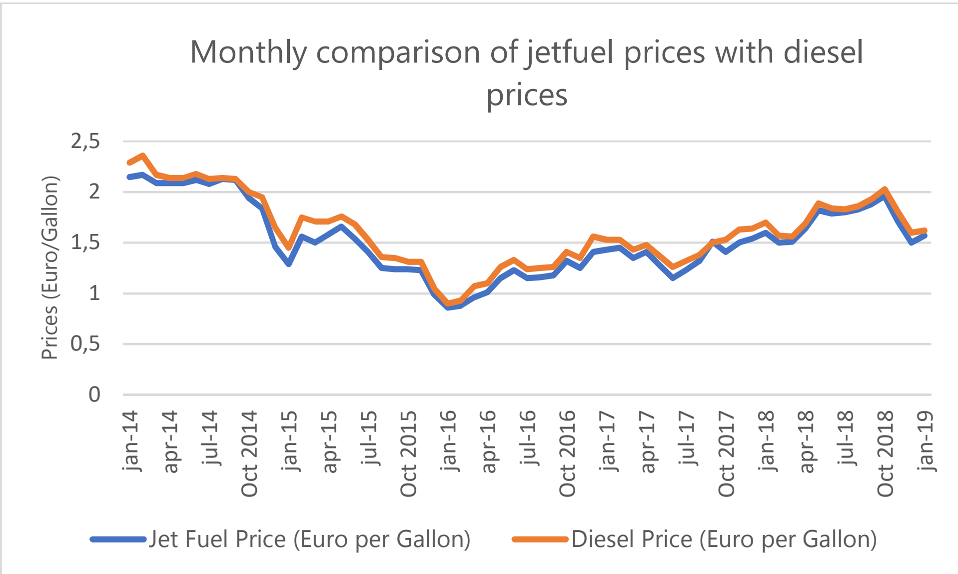

Figure 8. Monthly comparison of jet fuel prices with diesel prices (based on EIA, U.S. Gulf Coast Fuel Spot Price FOB)

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Advanced biofuel use in aviation (and also shipping) is included in the RED II voluntarily with a multiplier. The multiplier of 1.2 will help to reduce the price gap between advanced biofuels and fossil jet fuel, but a considerable premium remains. This premium still needs to be paid (e.g. through mechanisms described below (Klauber et al., 2017) otherwise, producers and suppliers cannot push volumes to the aviation sector.

- The Fly Green Fund, a Nordic initiative founded by SkyNRG, NISA, and Karlstad Airport in 2014, provides funding to companies, organisations, and individuals that fly on SAF. The main aim is to reduce environmental impacts of flying. 75% of the funds aggregated in the Fly Green Fund go into the procurement of SAF volume. The remaining 25% is invested in the development of SAF supply chains in the Nordic region. Swedavia, the largest Swedish airport operator, joined the Fly Green Fund as a launching customer, buying SAF for all staff flights. On an annual basis, Swedavia consumes approximately 150,000 U.S. gallons[10], resulting in a 1 million euro (10 million SEK) contribution per year over the course of three years. In 2016, Swedavia was the first company in the world to have its flights 100% powered by SAF(ref). The bio-based SAF consumption at Swedavia airports in 2016 was 450 tonnes, and currently new SAF initiatives are planned from 2018 onward (EASA, 2019).
- Norwegian airport operator Avinor has played a key role in a commercial offtake agreement by offering a unique airport incentive for all flights at Oslo Airport that are powered by SAF. Avinor has allocated up to 100 million NOK, approximately 10 million euros, over a 10-year period (2013– 2022) for initiatives and projects that can contribute to the realization of Norwegian biofuel. In 2016, Avinor supported the supplying parties, AirBP and SkyNRG, in two ways; 1) Avinor allocated a fixed amount per year to cover additional logistics costs, and 2) Avinor contributed money to cover the SAF premium for each liquid ton of SAF blended into the Avinor airport fuelling system. During 2016 and 2017 Avinor's Oslo and Bergen airports became the first in the world to offer SAF to all airlines on a commercial basis, and a total of 1.325 million litres of SAF was uplifted (EASA, 2019).
- Together with a yet-to-be-revealed central European airport, SkyNRG and Carbon War Room are currently advancing a program to integrate SAF into standard operations. The airport authority has aggregated funds to make a 1% SAF blend available to all aircrafts refuelling at the airport for the first five years, at no additional cost to the airlines. A federal fund responsible for the development and supervision of civil aviation activities in the country will cover 80% of the costs to enable the routine provision of SAF. The airport authority will directly finance the remaining 20%.
- IAG is part of a project with UK renewable fuels specialist Velocys to produce aviation fuel from household waste which will then be supplied to British Airways. Production should start in 2022, making it one of the first plants in the world dedicated to producing bio-based aviation fuel on a commercial scale. Ultimately, IAG hopes biofuels could provide up to 25% of its fuel by 2050 (EASA, 2019).
- Since May 2016, Airbus has offered customers the option of taking delivery of new aircraft using a blend of SAF. More than 25 aircraft have been delivered to date with 3 different airlines. Airbus, along with its partners are currently investigating how to scale-up sustainable fuel deployment across its sites and operations (EASA, 2019).

[10] 1 US gallon equals 3.78451 liters.

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Table 3. TRL and FRL of the six production pathways certified by ASTM for use in commercial flights (adopted from EASA, 2019 and SGAB,2017)

Name	Derived process	Blend ratio	Technology readiness level (trl)	Fuel readiness level (frl)	Notes
Approved by astm					
Ft-spk (synthetic paraffinic kerosene)	Fischer tropsch (ft) process	50%	6-8	7	
Ft-synthetic paraffinic kerosene aromatics (spk/a	Fischer tropsch (ft) process	50%	6-7	7	
Hydrogenated esters and fatty acids hefa-spk	The hvo process	50%	9	9	
Renewable synthesized iso-paraffinic (sip),	Sugar-based organics, notably farnesene produced by amyris	10%	7-8	5-7	Farnesene has a value as a chemical intermediate. Potential markets for farnesene in high price niche markets (e.g. Squalene at 30 usd/liter) may be more attractive than in commodity fuels markets (SGAB, 2017).
Alcohol to jet synthetic paraffinice kerosene (atj)-spk	Iso-butanol obtained via fermentation of sugars	30%	6-7	7	Cellulosic ethanol is currently more expensive than ethanol. Further post-processing to atj will increase the gap to the competing commodity.
Co-processing biocrude up to 5% by volume of lipid feedstock in petroleum refinery processes	Co-processing		7-8	6-7	Biomass to pyrolysis oil energy efficiency is around 65-70%. The overall efficiency (hydrocarbons/wood at plant gate) is around 30% in co-processing to around 60% for standalone integrated plants (natural gas used in the latter case is not included). There is the imitation that the FCC unit capacity would only allow production at low cost level of some 0.3-0.6 million tons maximum (SGAB, 2017).
In preparation					
Alcohol to jet synthesised kerosene with atj-ska (synthesised kerosene with aromatics),					
Hfp-hefa(fka hefa+),	Hvo diesel could be used more or less as-is but in a more limited blend ratio of the same order of magnitude as for sip				
Hydrotreated depolymerized cellulosic jet (hdcj),					
Hydro-deoxygenated synthesized kerosene (hdo-sk),					
Hydro-deoxygenated synthesized aromatic kerosene (hdo-sak),					
Ch catalytic hydrothermolysis					

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4.2. Shipping

The most important driver for advanced biofuel use in the shipping sector relates to the legislations mandating the reduction of non-GHG emissions. Biofuel use is one of the options to help meeting SO_x targets. Biofuel use in the shipping sector, however, is currently limited to some test runs. Companies like Good Fuels focus on diesel-type fuels such as HVO. Similar to the aviation sector, one of the most important barriers is the large price gap between biofuels and conventional fossil fuels used in shipping.

There are two types of main fuels used in the shipping sector. These are: (1) residual fuels that are generally of lower quality than distillate fuels, such as Heavy Fuel Oil (HFO); and (2) distillates, which are produced from a distillation of crude oil. Distillate fuels are generally of higher quality than residual fuels. Distillate fuels include different types of lighter shipping fuels, such as Marine Gas Oil (MGO), as well as variants within these residual and distillate products, such as Marine diesel Oil (MDO) that is a blend of HFO and MGO. Low-sulphur HFO (LSHFO) is an alternative fuel with the sulphur removed in the production process, which is used more since the onset of the IMO regulations on SO_x emissions. Low-sulphur MGO (LSMGO) and Ultra low-sulphur fuel oil (ULSFO) are also available bunker fuels that are used to comply with regulations (E4Tech, 2018).

Different than the aviation sector, the shipping sector can use a larger range of sustainable biofuels. Advanced biofuels that can be used in the shipping sector are introduced below[11]. However engines in marine vessels have a long life-time of around 20 to 30 years which leads to a very slow change across the vessel fleet. Hence, the introduction of new dual-fuel engines today will only have a marginal impact across the vessel fleet by 2030 (E4Tech, 2017).

[11] Also conventional biofuels, such as FAME, SVO can be used in shipping but not included in this sector as such biofuels are not part of this project focus.

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Table 4. List of advanced biofuels suitable for shipping sector(derived from E4Tech, 2018; SGAB, 2017)

Name	Type	Compatibility with ship engines and further requirements
HVO	Drop-in	Compatible with new and existing marine diesel engines that run on HFO, MDO or MGO (IEA, 2013).
Lignocellulosic ethanol		Compatibility of ethanol in engines and infrastructure is similar to methanol (see below). adaptation and installation costs of new dual fuel engines will be needed. Require demonstration projects to test ethanol in marine engines and the inclusion in the IGF code for the SOLAS regulation[12] (new mandatory code regarding safety in shipping) (E4Tech, 2018)
Biomethanol		Methanol contains oxygen and has a lower cetane number. This impacts energy density, (self-)ignition, combustion, emissions and other characteristics in comparison to conventional fuels (Ellis and Tanneberger, 2015). Therefore, it will not be possible to use them in traditional marine diesel engines without a pilot fuel or ignition enhancer and adaptions to the engine, injection, fuelling system and storage (Maritime Knowledge center, 2018). The low energy density of methanol (20 MJ/kg) in comparison to diesel or HFO (42.7 and 40.9 MJ/kg) requires around twice the space on board for fuel storage or an increased bunkering frequency for the same storage capacity. This would impact the loading capacity of the ship. Bio-methanol would be more attractive to the inland and short-sea shipping sectors as its 50% lower energy density (compared to the fossil incumbents) limits the vessels range required in deep-sea shipping.
Bio-Dimethylether (DME).		Properties are similar to Liquefied Petroleum Gas (LPG) (ETIP,2018). DME can be used in diesel engines as a substitute for diesel fuel due to its good ignition quality and a high cetane number. Compared to diesel fuel, DME has a lower viscosity and energy density (22.8 MJ/kg). As DME is gaseous in ambient conditions, it requires 5 bar pressure to remain in liquid state which makes storage, bunkering and transport more difficult (ETIP, 2018). Although more compatible with marine diesel engines than methanol it still requires adaptation of the engine and fuels system. It appears less attractive due to more complicated storage and bunkering.
FT diesel.	Drop-in	Would be compatible with all existing infrastructure both on the vessel as well as the port side (Ecofys, 2012).

[12] Amendments to the International Convention for the Safety of Life at Sea (SOLAS) require new ships using gases or other low-flashpoint fuels to comply with the requirements of the IGF code, which contains mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low-flashpoint fuels, focusing initially on liquefied natural gas (LNG).

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Name	Type	Compatibility with ship engines and further requirements
		Energy density (44 MJ/kg, LHV) of FT-Diesel is slightly higher than current marine fuels, while the volumetric density is slightly lower (IEA Bioenergy (2017). This leads to a 5% and 11% lower energy content on a volumetric basis compared to fossil diesel and HFO and would lead to slightly larger fuel tanks for a vessel to travel the same distance (E4Tech, 2018). Their commercial readiness will limit their availability in 2030
Upgraded pyrolysis oil	(Drop-in)	Crude pyrolysis oil can be upgraded and distilled to produce diesel, jet fuel and gasoline streams. This can be done either on-site at the fast pyrolysis plant or off-site in a conventional refinery. Crude pyrolysis oil would require adaptations in the engine and entire fuel system. Its significantly lower calorific value would lead to increased storage and transportation costs to be considered as a possible shipping fuel. Its high viscosity, emulsion with water at 20-30% and the fact it does not auto-ignite in a diesel engine make it much more challenging to replace fuel oils. Engines could be modified by adding a module with a special fuel/feeding system for crude pyrolysis oil. When upgraded its compatibility can be improved, and upgraded pyrolysis oil could get to a 'drop-in' fuel with similar characteristics as FT-Diesel, and could be compliant with EN590 (diesel standards for inland shipping) (E4Tech, 2018)
Bio-LNG		LNG vessels are marginal at the moment and the costs for converting existing vessels and infrastructure to LNG are significantly higher than for methanol due to the complex storage, bunkering and infrastructure requirements (E4Tech, 2018). would require significant increase in available LNG vessels and a high oil price environment to make bio-LNG an attractive option by 2030. Bio-LNG can be a potential option in short-sea and inland shipping, but more research is needed on the implications of LNG use on the current vessel fleets (E4Tec, 2018).

Production costs of advanced biofuels are, however, much higher than the market prices of conventional marine fuels. Figure 9 illustrates the price cost difference. In average drop-in biofuels are more than twice as high as the most expensive marine fuel (ULSFO). Because of the drop-in characteristics of the fuel produced, there is likely to be strong competition from both the road transport and aviation sectors. This could limit the fuel availability for the shipping sector, especially as the price differential for road transport and aviation fuel is lower (E4Tec, 2018).

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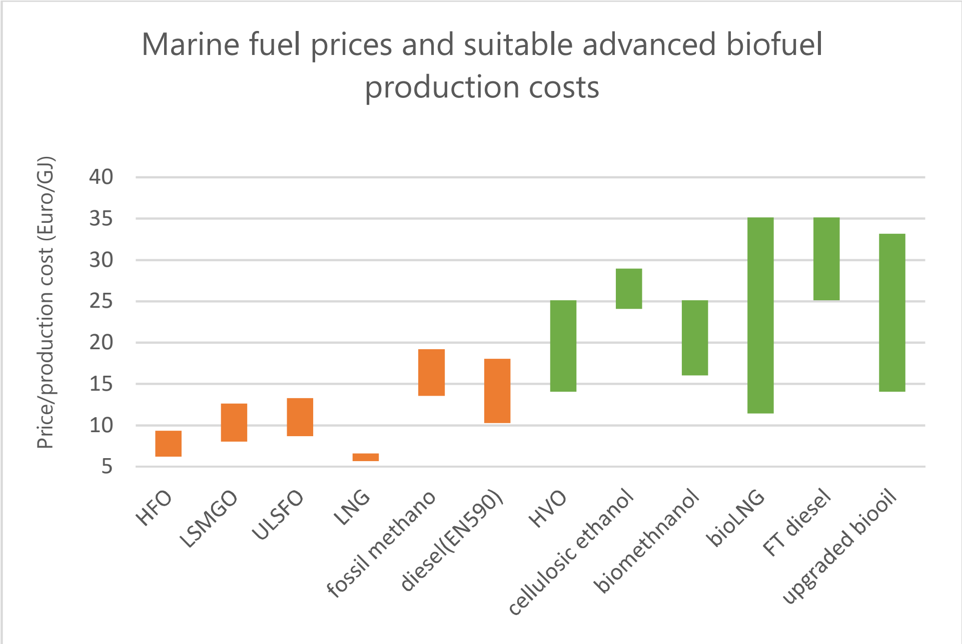

Figure 9. comparison of marine fuel prices with advanced biofuel costs (orange colour refers to conventional fossil fuels used in shipping whereas green colour refers to biofuels)

- *Marine fuel prices are derived from E4Tech,2018, where these were taken from the high and low from prices from the previous year ending March 2018 (approximately 45-70 $/bbl crude price during this period). These are Rotterdam prices where available from https://shipandbunker.com/prices/emea/nwe/nl-rtmrotterdam.*
- *Advance biofuel costs are derived from SGAB, 2017.*

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5. Future projections

This section focuses on model based scenario analyses conducted for the European Commission as well as the IEA, These scenarios present data regarding biofuel demand for 2030 and 2050. Neither the PRIMES scenarios conducted for the Commission nor the IEA scenarios detail the type of liquid biofuels (advanced versus conventional, lignocellulosic based versus oily feedstock based). Nevertheless, these scenarios provide valuable information in defining the order of magnitude of the demand for advanced biofuels. The scenarios also present the relative contribution of biofuels to other renewable and non-renewable options (i.e. energy savings and energy efficiency) in decarbonising the transport sector and reducing GHG emissions.

5.1. Primes reference 2016

The 'Reference Scenario' (EC, 2016) is one of the European Commission's key analysis tools in the areas of energy, transport and climate action. It builds upon a set of assumptions related to future population growth, macroeconomic and oil price developments, technology improvements, and current EU policies. The Reference Scenario acts as a benchmark of current policy and market trends. It starts from the assumption that the legally binding GHG and RES targets for 2020 will be achieved and that the policies agreed at EU and Member State level until December 2014 will be implemented. According to this scenario:

- Total final energy demand in transport presents a decreasing trend between 2010-2030 driven by the efficiency improvements of certain transport modes. The energy efficiency improvements for light duty vehicles[13] (driven by the CO_2 standards set for 2020/2021) contribute to the reduction of total final energy demand for transport until 2030 (Figure 10). Note that in December 2018 the European Parliament and the 28 EU member states agreed on new CO_2 emissions for cars and vans: new cars will have to decrease emissions in 2030 by 37.5% relative to 2021; and for vans the reduction target is 31%. Contrary to this, energy demand in freight transport[14] and aviation continues to increase. Efficiency improvements in aviation (11% in 2020 and 27% by 2030 relative to 2010) to some degree balances the strong activity growth. Final energy demand increases by 17% by 2030.
- Diesel is projected to maintain its share in total final energy demand in transport by 2030 (1/2 of total consumption),

The EU Reference Scenario 2016 distinguishes aviation activity into flights within the EU and international extra-EU destinations. Flights within the EU include domestic transport activity (within the boundaries of one single EU Member State) and international intra EU (both origin and destination of the flight is within the EU28). The international extra-EU air transport activity includes all remaining flights.

Fuels used for international shipping, by convention, are not accounted under final energy demand in the Eurostat energy balance. The PRIMES model estimates show a growth in the bunker fuels consumption, up to **70 Mtoe in 2050** (a growth of approximately 0.9 p.a.

13 In road passenger transport, energy efficiency of vehicles improves by 17% in 2020 and 29% in 2030 relative to 2010. Beyond 2030 it stabilizes due to the absence of further tightening of existing policies,

14 In December 2018 the Council of Ministers from EU member states have published their targets for trucks: CO_2 emissions of buses and trucks will have to decrease 30% in 2030 (and 15% by 2025),

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slowly decreasing during 2030-2050. It continues to be the main fuel for heavy duty vehicles (HDVs) (see Figure 11).

- LNG enters the market over the mid-to-long time horizon for road freight and inland shipping transportation. The share of LNG in total consumption of heavy duty trucks goes up to 2.8% and 8.2% in 2030 and 2050, respectively.

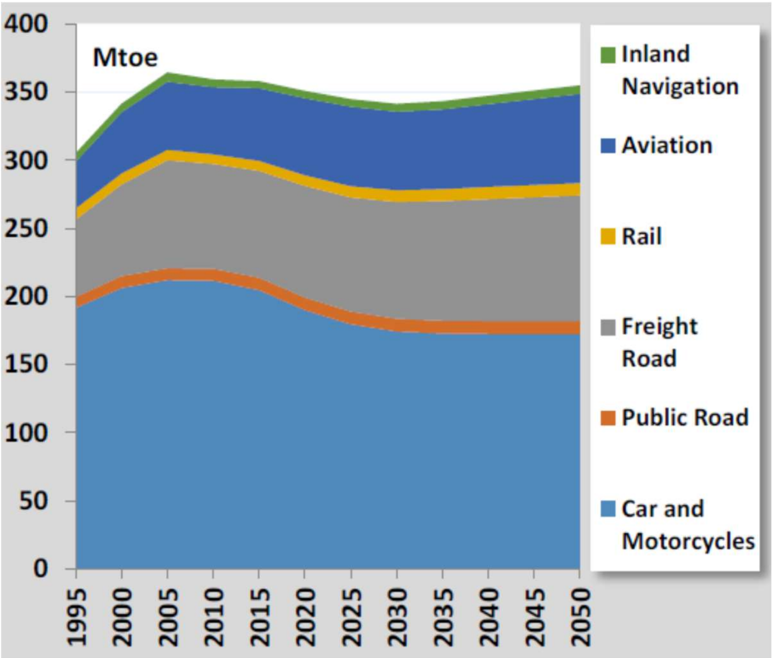

Figure 10. Final energy demand in transport sector in the time frame 1995-2050 (PRIMES, 2016)

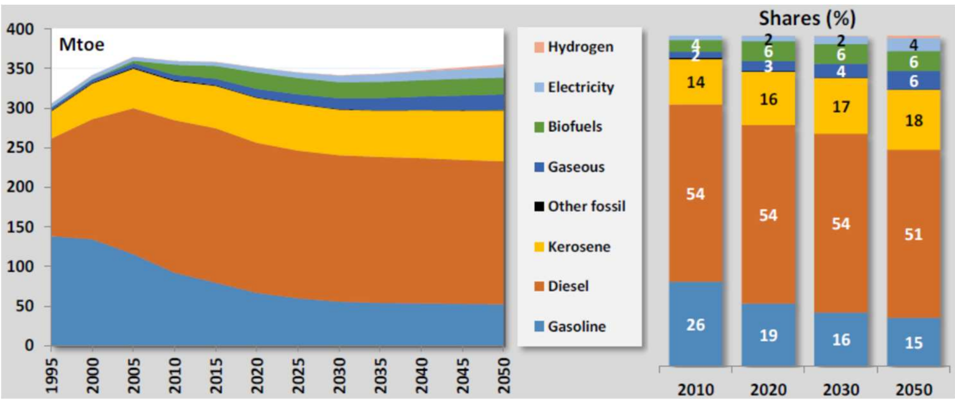

Figure 11. Final energy demand in transport broken down to type of fuels (PRIMES, 2016)

According to the PRIMES Reference Scenario, biofuel penetration is mainly driven by the legally binding target of 10% renewable energy in transport by 2020 and the Fuel Quality Directive (FQD) reduction targets (including the amendments in ILUC Directive). Beyond 2020 biofuel quantities in the EU remain stable as this scenario does not yet include the recent REDII. Only after 2035 biofuels slowly start penetrating the aviation fuel mix (driven by higher ETS prices).
Demand for heavy fuel oil in international shipping increases at low rates, as the demand for heavy fuel oil is progressively substituted by marine diesel oil and LNG. Demand for LNG for

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use as a marine fuel is expected to reach 7.3 Mtoe in 2050 (10% of the overall energy need of international maritime bunkers).

PRIMES Reference energy demand projections related to transport sector are presented in Table 5.

Table 5. Energy demand in transport according to PRIMES Reference 2016

	Unit	2015	2020	2030	2040	2050
Energy demand in transport	EJ	15,0	14,7	14,3	14,5	14,9
Road transport energy demand	EJ	12,2	11,8	11,3	11,4	11,5
Electricity in road transport	*%*	*0,0%*	*0,2%*	*0,9%*	*1,5%*	*2,3%*
Biofuels in total fuels (excl. Hydrogen and electricity)	*%*	*3,7%*	*6,1%*	*6,2%*	*6,3%*	*6,6%*
Rail transport energy demand	EJ	0,3	0,3	0,4	0,4	0,4
Aviation energy demand	EJ	2,2	2,4	2,4	2,5	2,7
Inland shipping energy demand*	EJ	0,2	0,2	0,2	0,3	0,3

* Fuels used for international shipping, by convention, are not accounted under final energy demand in the Eurostat energy balance. The UNFCCC registers CO_2 emissions from international bunkers only as "pro memori".

5.2. Energy strategy 2050

A number of scenarios have been analysed as part of the Communication "A Clean Planet for all" for the purpose of the development of the long-term strategy. A baseline scenario is developed using the macro-economic developments from the PRIMES Reference 2016. The main additions to Primes REF 2016 are the inclusion of the recently agreed directives (REDII and Energy Efficiency Directive). Thus, the below targets are incorporated into the baseline projections:

- at least 40% GHG emissions reduction in 2030 compared to 1990; with 43% GHG emissions reduction in ETS sector compared to 2005 and 30% GHG emissions reduction in effort-sharing sector compared to 2005;
- at least 32% renewable energy share in final energy consumption and at least 32.5% reduction in both primary and final energy consumption compared to (2030 projections established in) 2007 Baseline.

The scenarios are based on the baseline scenario and grouped into three. The first category addresses the *well below 2°C ambition*, it focuses on 80% GHG emission reduction by 2050 compared to 1990. The second category consists of one scenario. It combines the actions and technologies of the five scenarios of the first category into a sixth scenario (**COMBO**), without reaching though the level of deployment of each technology as in the first category. All pathways are assumed to be available and a GHG reductions can be achieved through all of them. This results in net GHG emissions reduction (including LULUCF) in 2050 close to 90% compared to 1990. The third category of scenarios achieves even stronger emissions reduction, reaching net zero GHG emissions by 2050 and thus *pursuing efforts to achieve a 1.5°C temperature change*. In this scenario category, remaining emissions that cannot be abated by

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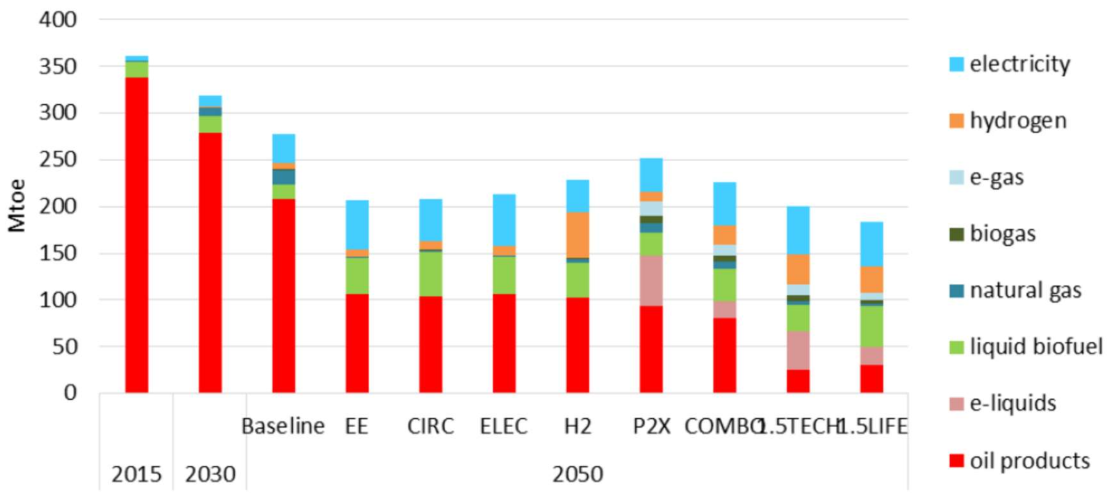
2050 need to be balanced out with negative emissions, including from the LULUCF sink. Further information of the scenarios can be found in Annex I.

The Baseline scenario presents the lowest share of renewable fuels in the transport sector (Figure 12). Liquid biofuels contribute to 6% of transport demand in 2050 (in EJ). In this scenario, around 11% of transport sector is electrified and H_2 use comprises around 2% of the fuel mix. Renewable energy from non-biological origin does not appear in this scenario.

The two scenarios focusing on the Paris Agreement (1.5TECH & 1.5LIFE) result in much lower energy demand and higher renewable fuels in 2050 compared to the baseline scenario. The share of liquid and gaseous biofuels is 26% of the total fuel mix in the 1.5LIFE scenario. Renewable fuels from non-biological origin (both liquid and gaseous) is also 26% of the fuel mix.



Source: PRIMES.

Figure 12. Comparison of fuels consumed in the transport sector in 2050, according to different scenarios

Aviation

Figure 13 illustrates the scenario results regarding aviation fuel mix in 2050. Penetration of renewables in the aviation sector is limited. In the Baseline scenario, only liquid biofuels (i.e. bio-kerosene) are projected to provide around 3% of the total energy demand in air transport by 2050. In the COMBO scenario, bio-kerosene would provide around 20% of the energy demand in 2050 and e-liquids around 5%. In the scenarios reaching net zero by 2050 much faster penetration of both bio-kerosene and e-liquids takes place by 2050, reaching 55-57% of the fuel mix (23-45% for bio-kerosene and 10-34% for e-liquids). In the 1.5LIFE scenario the significant uptake of liquid biofuels and e-liquids is coupled with a reduction in energy demand relative to 2015 (5% decrease by 2050), driven by the lower growth in transport activity and energy efficiency improvements.

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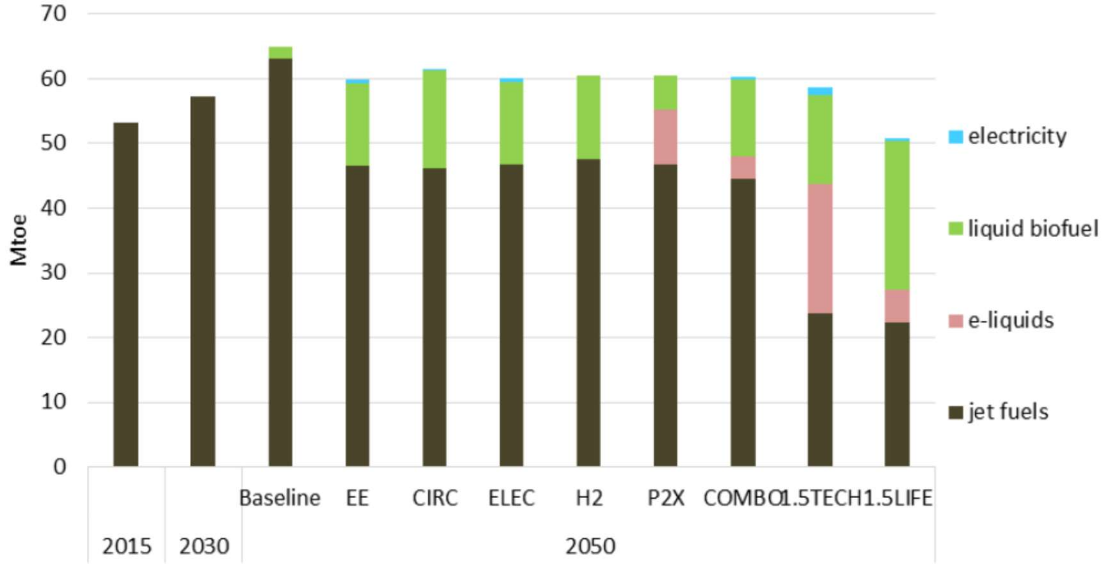

Figure 13. Aviation fuel mix in the Baseline compared to scenarios reaching up to -80% to net zero emissions by 2050 in 2050 (source: PRIMES)

(International) Shipping

The share of marine diesel oil in the EU international maritime fuel mix is projected to increase over time, while natural gas would provide around 11% of energy demand by 2050 driven by the Sulphur Directive and the assumed availability of refuelling infrastructure for LNG in the baseline scenario. Baseline scenario projects no renewable fuels in the shipping sector. The picture in the scenario where the Paris Agreement objectives are targeted to achieve is completely different. In this scenario (1.5LIFEMar) the total energy mix is projected to be reduced by 17% in 2050 compared to 2030. This is accompanied by 54% liquid biofuels in the fuel mix. This implies 21-30 Mtoe liquid biofuels demand by 2050. In this scenario e-gas and e-liquids also play a role, 10% and 17% of energy demand respectively.

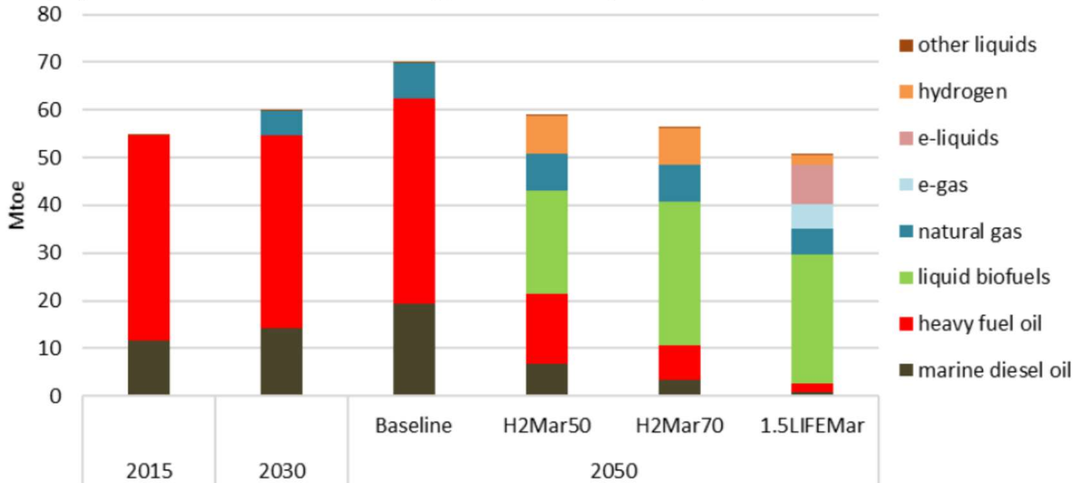

Figure 14. EU international maritime fuel mix in the Baseline and decarbonisation variants (Source: PRIMES)

5.3. IEA WEO 2018 projections

The IEA WEO2018 study includes 3 different scenarios. These are briefly introduced below.

- The Current Policies Scenario is based solely on existing laws and regulations as of mid-2018, and therefore excludes the ambitions and targets that have been declared by governments around the world. It provides a baseline for the *WEO* analysis.
- The new Policies Scenario: It includes the European Union's new, more ambitious 2030 renewable energy and energy efficiency targets. It also includes the recent policy developments in other world regions such as China, the US and Japan. This scenario results related the EU can be compared with the PRIMES baseline 2018.
- The Sustainable Development Scenario: it is based on achieving the Paris Agreement (goal of holding the increase in the global average temperature to "well below 2ºC". the EU related results of this scenario can be compared to PRIMES 2018 1.5 TECH and 1.5LIFE scenario results.

The EU28 related data are extracted and a brief comparison to PRIMES reference 2016 and 2018 projections within the clean energy Europe 2050 study is presented in Figure 15. PRIMES reference (2016) projects the transport energy demand to increase by 5% in 2050 (compared to 2030). In all other scenario runs, final transport demand is reduced. Total transport energy demand projections are in the range of 13-14 EJ in 2030 according to the PRIMES based scenario projections for the EU28. IEA new policy and sustainable policy scenarios indicate even lower figures, 11-12 EJ in 2030. Share of biofuels appear 6% in 2030 in PRIMES reference 2016 and 2018. IEA, WEO projects a higher amount of biofuels, with a range of 8%-18% in 2030. The 18% share relates to the sustainable development scenario.

Energy projections beyond 2030 include much more uncertainties as the assumptions become more uncertain. This can be observed also in the results. Final transport demand was projected to be in the range of 8-15 EJ in 2050. Baseline 2018, indicates a 13% energy efficiency compared to 2030 and 23% efficiency when compared with 2015. The policies dedicated to achieving the Paris Agreement goals indicate an energy efficiency and energy saving of around 37-42% when compared to 2030. Biofuels are projected to contribute to 6-26% of the total energy demand in transportation. The absolute range of liquid biofuels is 0.7-2 EJ in 2050. Interestingly, the higher figure relates to the scenario circular economy, not the Paris Agreement related scenarios.

Unfortunately, none of the scenario assessments touch upon the role of advanced biofuels versus conventional biofuels.

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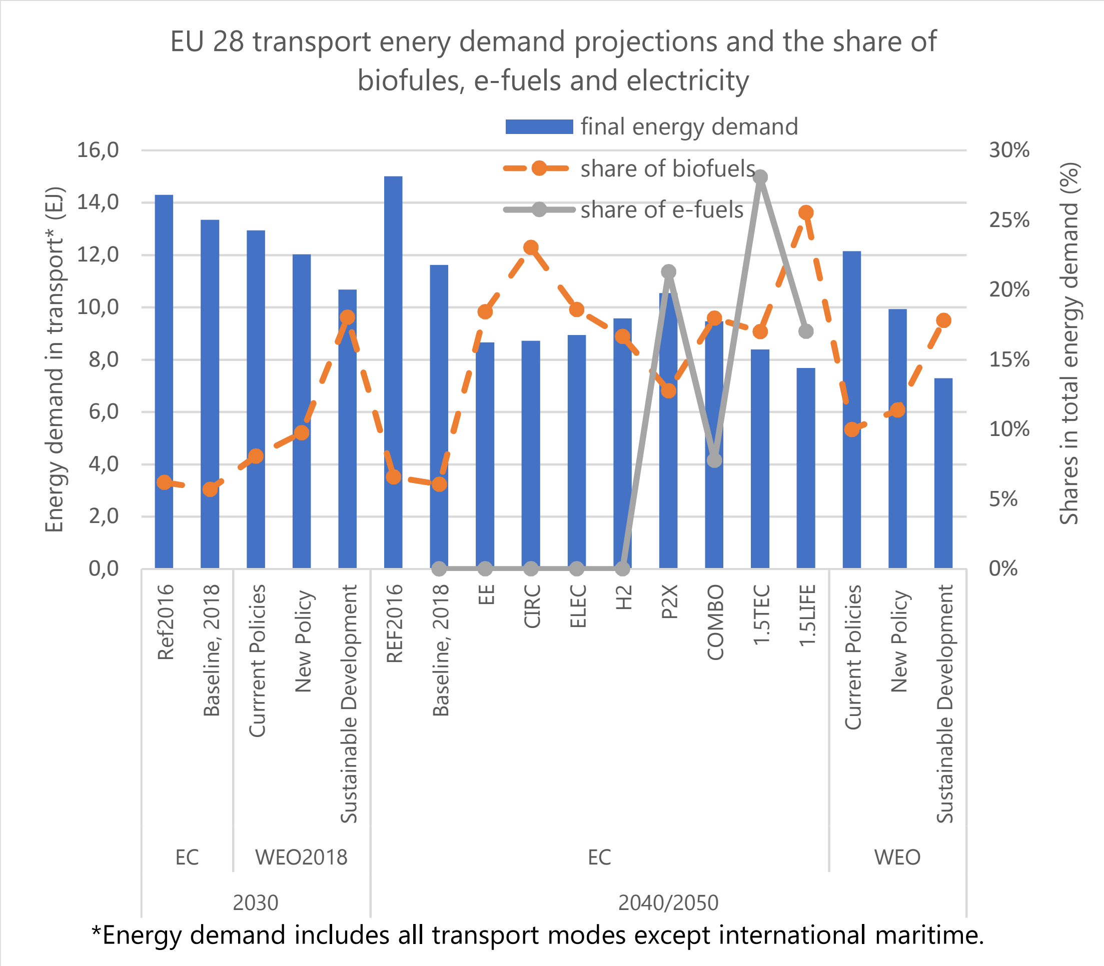

Figure 15. Transport energy demand projections and the share of biofuels and e-fuels

5.4. Synthesis of the projection results

Biofuel demand is projected to be higher in the IEA scenarios in 2030, with a range of 1-1.9 EJ. The high range relates to the sustainability scenario and reflects the path to achieve Paris Agreement goals. The PRIMES scenarios (reference 2016 and baseline 2018) projects lower demand for biofuels for 2030; 0.9 EJ in the reference 2016 run and 0.8 EJ in the baseline 2018 run. When compared to 2015, the PRIMES baseline 2018 projects a 8% increase of biofuels in absolute values in 2030 and reduction back to 2015 levels towards 2050. This fluctuation relates to the increasing role of electrification in road transport. In fact, the baseline scenario considers a more than fivefold increase in transport sector electrification by 2050 when compared to 2015. Next to that, H_2 appears in the market and meets around 2% of the total demand in 2050 in the baseline scenario run.

Contrary to the baseline scenario, all other PRIMES scenarios result in a much higher demand for biofuels in 2050. The demand range for biofuels is 0.7 EJ to 3 EJ in 2050. The 1.5 °C scenarios (that aim to achieve zero CO_2 emissions by 2050) define the biofuels demand as 1.4-3.2 EJ in 2050 when also international maritime is included. The IEA WEO projects a biofuels demand of 1.1-1.3 EJ in 2040.

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Figure 16 illustrates the range of biofuel demand projections in 2030 and 2050 according to the reviewed studies.

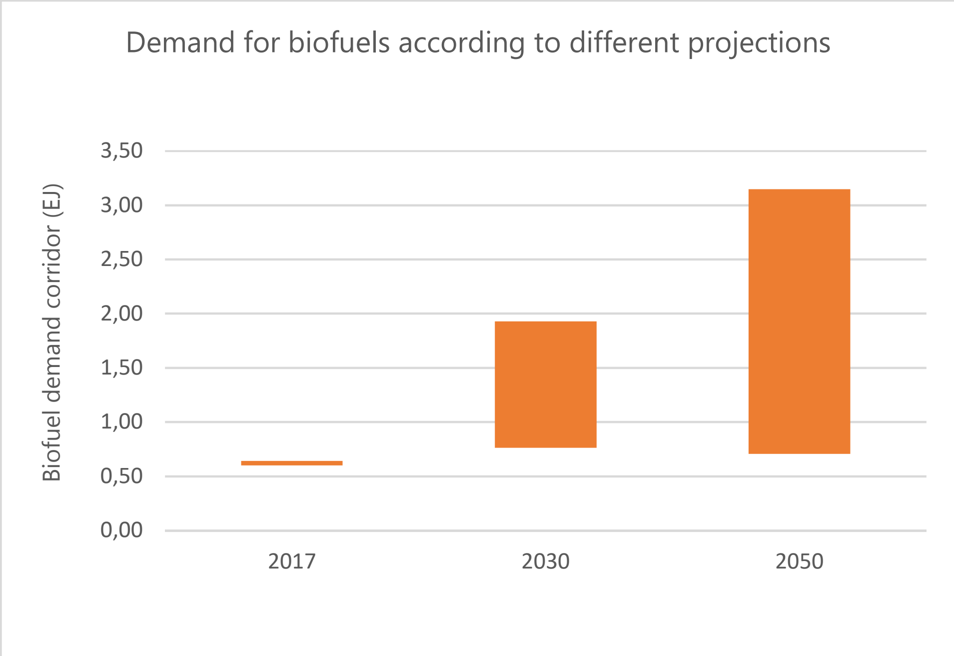

Figure 16. The range of demand projections for biofuels in 2030 and 2050 (2030 data derived from PRIMES and IEA projections; 2050 data derived from PRIMES, 2018 projections)

As stated before, there is no information detailing the types of biofuels projected in the transport fuel energy mix. However, the study indicated that biogas or biofuels produced from food crops will be very marginal in EU by 2050.

The role of renewable fuels of non-biological origin (referred to as RE e-fuels) will depend on the developments regarding CO_2 capture and electrolysers and the availability and most of all the price development of renewable electricity. PRIMES 2018 projects e-fuels (without referring to their renewability) only in 2050 and in a limited number of scenarios. Such fuels appear in the P2X scenario and also scenarios that assume GHG emission reductions higher than 80%. In the P2X scenario the amount of e-fuels appear even higher than biofuels (2.2 EJ). In the Combo scenario it is 0.7 EJ and in the 1.5ºC scenarios it is 1.3-2.4 EJ. Figure 17 illustrates the role of e-fuels in different PRIMES scenarios.

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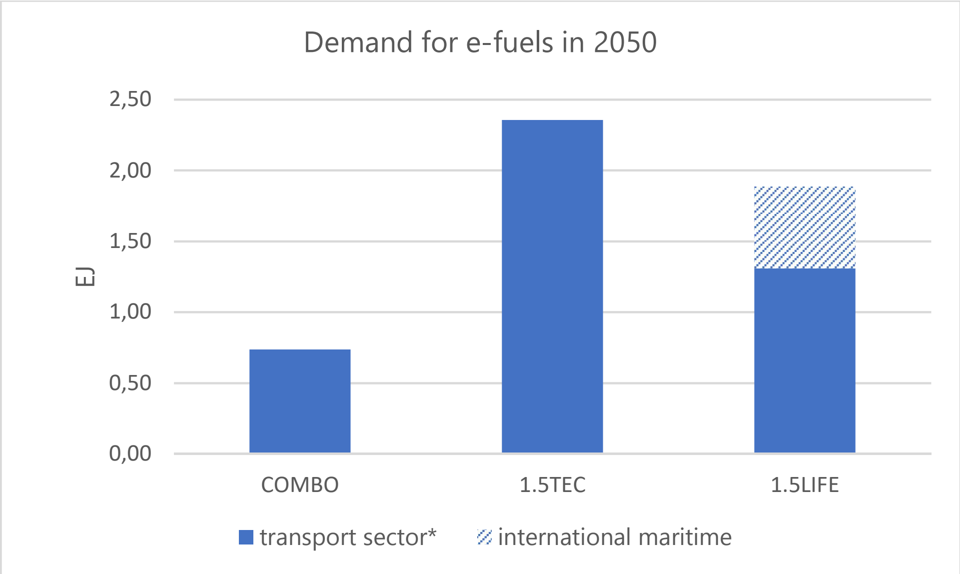

Figure 17. Role of e-fuels in PRIMES 2018 runs

- Refers to transport sector as included in PRIMES projections (excluding international maritime).

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6. Conclusions

The future market roll out of RESfuels depends very much on stable and long term policy support. The advanced fuel sub-obligation introduced in REDII is a good start in that regard but not yet sufficient for a substantial contribution to the Paris Agreement ambitions. Next to that a 60% GHG emission reduction target by 2050 for the transport sector is insufficient to reach 1.5ºC goal.

RESfuels are among the most viable options to reduce GHG emissions in the transport sector. While electrification becomes more significant, (mainly in road and rail transport), advanced biofuels appear to be the most viable option for shipping and aviation sectors. However, high production costs of advanced biofuels and the current low fossil fuel prices have been a considerable obstacle to their development and deployment. Their future ability to compete in the market will depend on cost reductions (due to technological learning, economies of scale, efficiency improvements, more affordable novel sustainable feedstocks etc.) and the fossil fuel price developments. Still, their competitiveness may be difficult, especially for the aviation sector. The historical data shows that kerosene prices have been equal to or less than the price of diesel whereas further processing of advanced biofuels to be used in the aviation sector is more costly and more energy intensive. Developments in the shipping sector up till now relate to reducing air pollutant emissions rather than GHG emissions. Still, biofuels for shipping can be a viable option. The wide technical specifications for shipping fuels can enable use of advanced fuels with lower production costs. An important factor here is that the total demand from this sector is large.

A number of scenario conducted for the Commission and by the IEA indicate the need for large quantities of RESfuel demanded by 2050. The PRIMES scenarios that aim to achieve the Paris agreement goals projects a major increase in current biofuel use. If the 2050 demand is considered to be met completely by advanced biofuels, this implies a more than 10 fold increase of their uptake in the time frame between 2017-2050. More specifically, the 2050 projections that focus on achieving the Paris Agreement Goals are as follows:

- Liquid biofuel demand from all transport modes, excluding international shipping, is projected to be in the range of 1200-1800 PJ. For the aviation sector, biofuel demand appears to be in the range of 580-960 PJ and the liquid e-fuels 220-850 PJ.
- The international shipping demands another 930-1300 PJ liquid biofuels. Liquid e-fuel demand is projected in one scenario, with an amount of 350PJ.

In conclusion, biofuels and e-fuels are among the important fuels to decarbonise the transport sector in Europe. In addition to all possible renewable fuel options maximising energy efficiency and energy saving is absolutely crucial. The 2050 scenarios indicate significant fuel consumption reductions. The scenarios that focus on the achievement of the Paris Agreement indicate the need for energy reduction of above 40% in 2050 when compared to 2015.

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Annexes

Annex I. EC, 2018 Main elements of the scenarios

	Electrification (ELEC)	Hydrogen (H2)	Power-to-X (P2X)	Energy Efficiency(EE)	Circular Economy (CIRC)	Combination (COMBO)	1.5°C Technical (1.5TECH)	1.5°C Sustainable Lifestyle (1.5LIFE)
Main drivers	Electrification in all sectors	Hydrogen in industry, transport and buildings	E-fuels in industry, transport and buildings	Pursuing deep energy efficiency in all sectors	Increased resource and material efficiency	Cost0efficient combination of options from 2°C scenarios	Based on COMBO with more BECSS, CCS	Based on COMBO and CIRC with lifestyle changes
GHG targets in 2050	80% GHG (excluding sinks)["well below 2°C" ambition]					-90% GHG (incl. sinks)	-100GHG (incl. sinks)["1.5oC"ambition]	
Major common assumptions	•Higher energy efficiency post 2030 •Deployment of sustainable, advanced biofuels •Moderate circular economy measures •Digitalization				•Market coordination for infrastructure deployment •BECCS present only post-2050 in 2°C scenarios •Significant learning by doing for low carbon technologies •Significant improvements in the efficiency of the transport system.			
Power sector	Power is nearly decarbonized by 2050. Strong penetration of RES facilitated by system optimization (demand-side response, storage, interconnections, role of prosumers). Nuclear still plays a role in the power sector and CCS deployment faces limitations							
Industry	Electrification of processes	Use of H_2 in targeted applications	Use of e-gas in targeted applications	Reducing energy demand via energy efficiency	Higher recycling rates, material substitution, circular measures	combination of most Cost-efficient options from "well below 2°C" scenarios with targeted application (excluding CIRC)	Combo but stronger	CIRC+COMBO but stronger
Buildings	Increased deployment of heat pumps	Deployment of H_2 for heating	Deployment of e-gas for heating	Increased renovation rates and depth	Sustainable buildings			CIRC+COMBO but stronger
Transport sector	Faster electrification for all transport modes	H_2 development for HDVs and some for LDVs	E-fuels deployment for all modes	Increased modal shift	Mobility as a service			CIRC+COMBO but stronger Alternatives to air travel
Other drivers		H_2 in gas distribution grid	E-gas in gas distribution grid				Limited enhancement natural sink	Dietary changes Enhancement natural sink

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