Renewable Fuels Paper

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Outline

Executive Summary

In the world and in the EU in majority fossil liquid and gaseous fuels are the dominant fuels used in the transport sector. Renewable fuels only contribute about 5-6% of total energy need. Worldwide ethanol is the largest renewable energy use, followed by biodiesel, other liquid fuels, renewable electricity and biomethane. In Europe biofuels replacing diesel are the largest used renewable fuel, while ethanol consumption is at about one fourth of that of biodiesel. Renewable electricity is still at low levels when viewing road transport and will still be at relatively modest share in 2030, leaving a necessary role for low-carbon liquid and gaseous fuels in transport. (see chapter 1)

The new Renewable Energy Directive (RED2) aims to achieve higher shares of renewable energy in transport by 2030. RED2 limits the use of biofuels produced from food and feed crops, as well as the use of biofuels based on used cooking oil and animal fats. This implies producing biofuels from other feedstocks, in particular waste and residue based biogenic resources. Subsequently this requires developments in new and/or adjusted conversion technologies to produce fuels that can be blended or used as drop in fuels. The identification of these feedstock technology combinations has only started recently and will continue in the next decade(s), as in many cases the technology status has not yet reached full market/commercial operation levels. (see Ch. 1 and 2)

RED2 foresees a role for synthetic, renewable, non-biogenic fuels and even recycled carbon fuels as a means to reduce further use of virgin fossil resources. (see Ch. 2)

Chapter 3 provides details on how the greenhouse gas saving is treated in the current RED and in the upcoming Red. It clarifies the difference between default values, typical values and actual values and provides clarity on the fossil fuel comparator and the threshold levels to be reached for biofuels to be characterized as sustainable. While in this chapter to potential for waste-based methane, a gaseous fuel, is expressed, the chapter also highlights that for some of the new fuel categories – such as renewable fuels of non-biological origin, recycled carbon fuels, and co-processed biofuels – information from the European Commission is awaited (in the form of so-called delegated acts) in the next years to better understand how these technologies are expected to contribute in achieving climate neutrality in transport in Europe.

Chapter 4 provides clarity with respect to the production costs of new biofuel conversion routes. In general the cost of biofuel is mainly governed by the costs of the resource and the cost of capital for the conversion facility. With the intended switch to waste based feedstocks the resource cost may go down, though the cost of capital for new and more innovative technologies might be substantially higher.

Looking forward to 2030 and even 2050 (chapter 5) it is discussed that total transport volumes and the corresponding energy use might remain rather flat in the coming decades: energy efficiency gains are balanced with growth in mobility. Though large growth characteristics are expected for electric mobility, in the initial years this may be still at a too low pace to sufficiently decrease pressure from greenhouse gas emissions. This requires the simultaneous contribution of low-carbon liquid and gaseous fuels. Especially in the long distance transport segments these fuels are expected to provide energy to vehicles for a long period to come, due to the need for high energy dense energy carriers.

1 Brief and descriptive overview of production pathways for biofuels and recycled carbon fuels

1.1 Introduction

In today's world in majority fossil fuels are used to produce liquid and gaseous fuels for the transport sector. As can be seen from Figure 1 about 96% of the world's transport energy use origins from fossil fuels. Worldwide ethanol is the largest renewable energy use, followed by biodiesel, other liquid fuels, renewable electricity and biomethane.

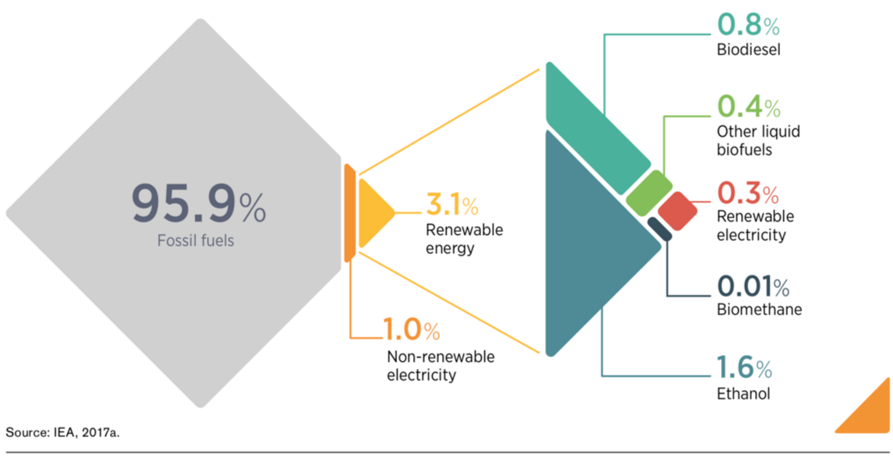


Figure 1 Transport energy use worldwide by transport fuel, 2015

In Europe the situation is similar with respect to the share of fossil fuels and renewable energy, but it is different from the renewable fuels used.

According to data published in the 2018 Transport in Figures, statistical pocketbook (EC, 2018b) the share of fossil fuels was 94.4% in 2016, whereas the share of biocomponents in diesel (mainly FAME) was 3.6%, the share of biocomponents replacing gasoline (mainly ethanol) was. See Figure 2. The share or electricity is mainly related to rail transport.[1] No information yet is available on the amount of electricity used in road transport.

[1] The share of electricity in rail transport is estimated at 50%, based on https://ec.europa.eu/transport/facts-fundings/scoreboard/compare/energy-union-innovation/share-electrified-railway_en. The share of renewable energy in transport for 2016, 29.56%, is taken from the EU SHARES date for 2016, see https://ec.europa.eu/eurostat/web/energy/data/shares. According to the data in the 2018 Transport in Figures document, the share of energy of rail transport in total transport is 2%. This explains the 1% used in Figure 2.

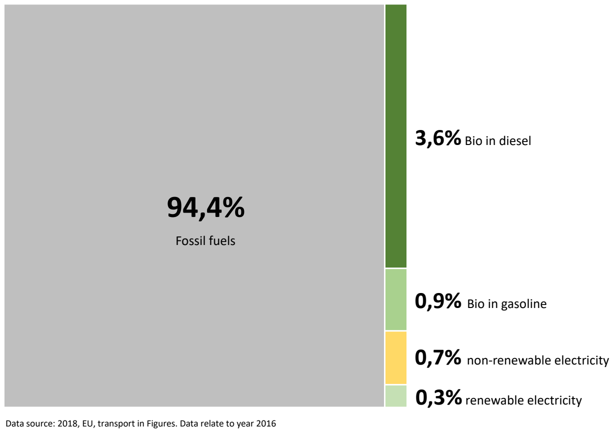


Figure 2 Transport energy use in EU by transport fuel, 2016

The Renewable Energy Directive for the period 2021-2030 (RED2) sets higher ambitions for the share or renewable energy in transport: by 2030 a share of at least 14% renewable energy should be achieved. In the next chapter more details are provided on the details, type of fuels and specific conditions that have been set to achieving this. Here it is important to note that the year 2030 is a first milestone in achieving a climate-neutral Europe by 2050.[2] It will require that the share of renewable energy in transport will need to increase further. While it is acknowledged that that will partly be met by the introduction of renewable electricity (starting in the lighter transport segments) it will require the introduction of renewable and low carbon fuels. The next section will briefly describe which pathways are currently available or under development to produce such renewable and low carbon fuels.

1.2 Overview of pathways[3]

Resource Base

The production of renewable and low-carbon fuels starts with feedstocks in which energy is stored as a chemical component or in the form of electricity:

- Biogenic feedstocks. The basic types of feedstocks used for the production of gaseous and liquid fuels are the following, which can further be characterised by being a primary feedstock (crop), a by-product or a waste/residue. Each of these require specific conversion technology:
  - Oils and fats (from vegetable or animal origin)
  - Starch-based biomass
  - Lignocellulosic and woody biomass
  - Organic matter available in wet conditions (like manure or sewage sludge)
- Renewable electricity (for the production of e-fuels)
- Industrial, fossil based feedstocks:
  - waste gases from industrial activities (e.g. CO from steel production)

[2] https://ec.europa.eu/clima/policies/strategies/2050_en
[3] More detailed and in-depth information of these pathways can be found in the following report: DBFZ, 2018, Monitoring Biokraftstoffsektor, 4. Auflage

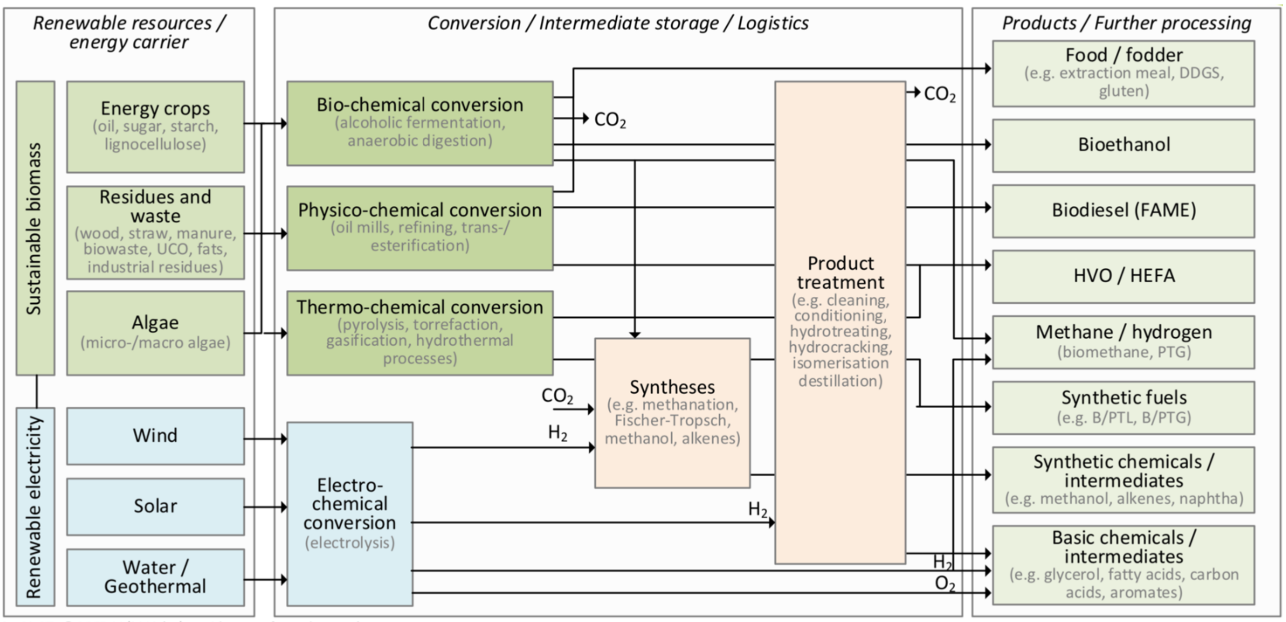
- non-recyclable plastics

Conversion pathways and resulting fuels/products

In the next section an overview of the basic conversion technologies is shown (see Figure 3), also showing possible synergies. This overview does not include the conversion technologies for the production of recycled carbon fuels. However, in most cases the industrial gases and plastics are fed into thermo-chemical conversion technologies (often gasification), from which the feedstocks are taken to form final products.

The resulting transport fuels are:

- Gasoline replacing fuels:
  - Bio-ethanol, currently allowed up to 5% (on volume basis) or in some countries up to 10% (on volume basis), or available as E85, for which vehicles need to be adapted, like flexifuel cars
  - Bio- or renewable methanol, which can be used as component for MTBE, or as direct blend component (though limited to small percentage in gasoline
- Diesel replacing fuels:



SynBioPTx © DBFZ 01/2019 (w/o entitlement of completeness)
B/PTG – Biomass-/Power-to-Gas, B/PTL – Biomass-/Power-to-Liquids, DDGS - Dried Distillers Grains with Solubles, FAME – Fatty acid methyl ester, HVO / HEFA - hydrotreated vegetable oils / esters and fatty acids, UCO – used cooling oil

Figure 3 Technical Routes and Synergies of BtX and PtX-conversion routes (Source DBFZ, 2019)

  - FAME, Fatty Aced Methyl Esther, which can be blended up to 7% under the EN590 diesel blend, or used in high blends like B30 or B100 for specific and adjusted captive fleets, like buses.
  - Hydrogenated renewable oils (HVO), which are similar to other paraffinic fuels like GTL. HVO complying to the EN15940 standard can be added to diesel up to approx. 30 - 40% and still comply to the EN590 diesel standard. Many Heavy Duty Truck OEMs have allowed up to 100% HVO

for use in their Euro V and IV truck engines[4]. So far only a few passenger car brands to date (Peugeot, Citroën, Volvo) have allowed this also for their Euro6 engines.

Current challenges and technology status

The upcoming RED2 sets limits to certain feedstocks to be used, in particular food/feed crops based biofuels (mainly used for the production of FAME, HVO and ethanol) and used cooking oil and animal fats (mainly used for the production of FAME and HVO), indicating that the achievement of the RED2 2030 targets will depend on the deployment of biofuels produced from feedstocks listed in Annex IX-A, renewable fuels of non-biological origin and recycles carbon fuels.

DBFZ has provided and overview of the current technology status, as is presented in the following figure (see Figure 4)[5]. Even though the graphs provides data for the German situation, it provides insights in the technology status for Europa as a whole.

In this overview both biofuels and renewable fuels of non-biological origin (a definition used in the RED2, also known as electrofuels or e-fuels) are presented.

With respect to the technology status of Recycled Carbon fuels the 2018 update of the 2017 SGAB-report on the technology status of advanced biofuels, renewable fuels and low-carbon fuels provides valuable information. This report has been published under the ART Fuels Forum, a project supported by DG Energy of the European Commission[6].

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[4] In the case of 100% HVO, the fuel needs to comply to the EN15940 standard (XTL-fuels)
[5] In Figure 4 for the various options the Technology Readiness Levels (TRL) and Fuel Readiness Levels (FRL) are mentioned. TRL levels vary between 1 and 9 and reflect the status of the technology development, from fundamental research (TRL1-3), via piloting (TRL4-6) to various stages of demonstration (TRL7-9). In annex A, each TRL is described. Fuel Readiness Levels follow the same principle. The Commercial Aviation Alternative Fuels Initiative (CAAFI) has described the different levels, also varying from 1 to 9, see http://www.caafi.org/tools/Fuel_Readiness_Level.html
[6] ART Fuels Forum: Alternative and Renewable Transport Fuels Forum: www.artfuelsforum.org

Option	Feedstock according RED II Annex IX and others[a]	TRL/FRL[b]	Capacity (production) EU in PJ/a[c]	Development perspectives within RED II
Conventional biofuels	**Consumption DE 2017[c]: 113 PJ (of which 30% based on residues)**			
Bioethanol	Sugar cane/beet, corn, grain	9	321 (140)	Stillage for biogas and/or bio-CO_2
Biodiesel (FAME)	Vegetable oils, UCO, animal fats	9	955 (340)	Use of UCO
HVO/HEFA	Same like FAME	9	172 (123)	Use of UCO and feedstocks for advanced fuels
Advanced fuels and PTx	**Consumption DE 2017[c]: 1,6 PJ**			
Bioethanol	Lignocellulosic, e.g. straw	7 - 9	6	s.a., competivness to conventional ethanol
HVO/HEFA	Biocrude oil, like tall oil, algae oil, HTL	8 for tall oil 3-4 for others	7	PT-H_2 for hydroprocessing
Biomethane / Biogas	Manure, maize, biowaste, stillage	9	44	bio-CO_2 for SynBioPTx/advanced fuels
BTG (SNG)	Lignocellulosic (wood, straw)	6 - 7	0.01	PT-H_2 integration, synthesis
BTL (FT, Methanol, D/OME)	Like BTG, also waste streams	3 - 5	0.003	PT-H_2 integration, synthesis
PTG (H_2, SNG)	electricity, CO_2	8 - 9	0.33	Use of bio-CO_2, synthesis
PTL (same like BTL)	electricity, CO_2	TRL 8-9 components, FRL 2 (methanol 8-9)	0.8 (methanol), ~0	Use of bio-CO_2, synthesis

Figure 4 Technology status of various conversion routes (Source DBFZ, 2019), abbreviations as in Figure 3.

[b] TRL: Technology Readiness Level, FRL Fuel Readiness Level

2 Legislative context of renewable and low-carbon fuels

2.1 Key ‘take aways’ from the legislative context

In this chapter a brief history of the European legislative context is provided, going back to the initial publication of the Biofuels Directive in 2013.

Centrale take-away messages are:

- The policy support for the production and use of biofuels goes back to the early nineties of the previous century – at that time mainly at national level and very strong connected to the agricultural sector
- With the Renewable Energy Directive a more international perspective was introduced, initiating more trade in feedstocks and biofuels from outside Europe.
- Over the years the support scheme move from taxation support to obligations and mandates, which are still increasing
- The new Renewable Energy Directive (for 2021-2030) has set limits to biofuels from food and feed crops and aims more on the production and use of advanced fuels, produced from specific waste and residues based feedstocks
- Also gives the new Renewable Energy Directive gives room for more types of renewable fuels (a category now dominantly almost 100% housed by biofuels. The development of these electrofuels towards cost-effectiveness may take the coming decade, but needs to be started now. A second category the commission aims to support is the recycled carbon fuels, as a new form of low-carbon fuels replacing fossil fuels.

An overview of the mandates over time is given in Table 1:

Table 1: Details of the various biofuel related EU-directives over time

		Biofuels Directive 2003	**Renewable Energy Directive 2011-2020**	**Renewable Energy Directive 2021-2030**
Year of publication		2003	2009 amended in 2015	2018
Target for share of renewable energy		5.75% in 2010	10% in 2020	At least 14% in 2030
Additional issues:				
	Limit on food and feed crop based biofuels	-	max 7% (mentioned in amendment)	max 7% but based on 2020 levels in MS (+1%pt)
	Limits on waste-based biofuels in Annex IX-B			max 1.7% (MS may request deviation from this)
	Sub-targets for Annex IX-A biofuels		0.5% in 2020 (mentioned in amendment	At least 0.2 % in 2022 at least 1 % in 2025 at least 3.5 % in 2030 (but when reported to EU by MS, so included double counting)
Multiplier factors				
	electricity		Must count 2.5 times in road, 1.5 times in rail	Must count 4 times in road, 1.5 times in rail
	Annex IX fuels (A and B list		May count twice	May count twice

Use of biofuels in aviation and maritime		Must be multiplied by factor 1,2	Must be multiplied by factor 1,2
Greenhouse gas saving (well to wheel)		> 35% (compared to fossil fuel comparator of 83.8 gCO_{2eq}/MJ) up to 2017 > 50% (compared to fossil fuel comparator of 83.8 gCO_{2eq}/MJ from 2018 onwards	With fossil fuel comparator of 94 gCO_{2eq}/MJ: at least 50 % for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations in operation on or before 5 October 2015; at least 60 % for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations starting operation from 6 October 2015 until 31 December 2020; at least 65 % for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations starting operation from 1 January 2021; at least 70 % for electricity, heating and cooling production from biomass fuels used in installations starting operation from 1 January 2021 until 31 December 2025, and 80 % for installations starting operation from 1 January 2026.

2.2 Introduction and description of historical development of biofuels policy

The European legislation on renewable fuels in transport dates back from the 1990's. In various EU Member States regional developments with the production of crop-based biofuels took place, mostly based on ethanol from sugar beet and starch (from corn and wheat) or biodiesel from rapeseed oil and sunflower oil. The biofuels options was one of the options the European agricultural sector explored to diversify its market and to build extra variety in the existing agricultural rotation schemes. Capacities of the production facilities where based of regional operation and member states had specific, country-oriented support mechanisms in place. In Germany e.g. tax exemptions where provided for biodiesel (FAME) if it was used in a 100%-form in adapted vehicles that where capable of processing FAME as well as standard diesel. In a later stage, mainly due to pressure from the car industry that it would be better and economically more feasible to fuel every car with a share of X% biofuel blend than to build separate types of each model.

In 2003 the European Commission harmonised the development of biofuels with the publication of the Biofuels Directive[7], aiming at achieving a share of 5.75% of biofuels in 2010. The main drivers behind the 2003 Directive were:

- Reducing the dependence of oil imports
- Diversifying the energy sources used in transport
- Reducing climate emissions

[7] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32003L0030

- Enhancing the economic circumstances in the rural sectors in Europe.

In 2009 the support for biofuels in transport became part of the broader Renewable Energy Directive[8], which set new targets for 2020 and aimed at (i) achieving an overall 20% share of energy of renewable original in the final energy use (with targets varying per Member State), (ii) reduction of greenhouse gas emissions by 20% as compared to 1990-levels, and (iii) a specific sub-target for renewable energy in transport of 10%. The RED also introduced, for the first time, specific sustainability criteria for biofuels and bioliquids, to ensure the environmental performance of biofuels, with minimum thresholds for the well-to-wheel greenhouse gas emission savings as compared to the fossil alternatives. The sustainability criteria secured that all actors in the supply chain had to be certified by certification schemes that were approved by the European Commission.[9]

In 2015 the 2009-RED was amended, following a decade-long debate about unwanted impacts related to indirect land use change. The main points of this directive was to set a cap on the share of food/feed crops fuels (max 7%) and to introduce sub-targets for advanced biofuels, based on waste and residues. A list was provided (so called Annex IX fuels) for feedstocks that could be the basis of such advance fuels.

While in all these directives the main focus and debates has been on biofuels, it is worthwhile to mention that already in the 2003-Directe specific attention was given to 'other renewable fuels'. Even though not contribution in large to the achievement of the renewable energy targets, the option for these fuels have always been there. In the 2009 Directive additional support to renewable electricity was provided, via the multiplier factor of 2,5 (reflecting the higher energy efficiency performance). In the 2015-Directive another category of fuels was introduced: renewable fuels of non-biological origin (RFNBO's). those fuels are now known as e-fuels or electrofuels, and are liquid or gaseous fuels that are based on renewable electricity.

In the 2018 published Renewable Energy Directive for the period 2021-2030[10] another category of fuels is introduced: Recycled Carbon Fuels. These fuels, as well as the full details of this RED2, are discussed and presented in the next section.

2.3 The Renewable Energy Directive for the period 2021-2030

The new RED-II has some changed implications for the production and use of sustainable biofuels. Here are the most relevant issues:

- A binding overall Union 2030 target for renewable energy of 32% (Article 3);

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[8] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0028

[9] Information about the sustainability criteria and the approved sustainability schemed can be found at https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels

[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.328.01.0082.01.ENG&toc=OJ%3AL%3A2018%3A328%3ATOC.
The recast of Renewable Energy Directive (RED-II) for the time frame 2021-2030 has been published in the https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

- the share of energy from renewable sources in final consumption of energy in the European Union as a whole – not at individual Member State level – in 2030 should be at least 32%;
- Renewable energy in the transport sector of at least 14% (Article 25 to 29).

Each Member States shall set an obligation to fuel suppliers to ensure that the share of renewable energy within the final consumption of energy in the transport sector is at least 14% by 2030 (minimum share) in accordance with an indicative trajectory set by the Member State and calculated in accordance with the methodology set out in the articles 25 to 27 of the directive. For the calculation of the minimum share, Member States:

- shall take into account renewable liquid and gaseous transport fuels of non-biological origin also when they are used as intermediate products for the production of conventional fuels, and
- may take into account recycled carbon fuels.

A sub-target for advanced biofuels

Within the minimum share of 14% mentioned above, the contribution of advanced biofuels and biogas shall be at least 0.2% in 2022, at least 1% in 2025 and at least 3.5% in 2030. Biofuels are only considered 'advanced', when produced from feedstocks listed in Part A of Annex IX of the directive.

Conditions for biofuels from food and feed crops

Specific rules are described for biofuels, bioliquids and biomass fuels produced from food and feed crops (Article 26).

The share of biofuels and bioliquids - as well as of biomass fuels consumed in transport - when produced from food and feed crops is capped:

- the share cannot be more than 7% of final consumption of energy in the road and rail transport sector in a specific Member State.
- However, the actual cap in a Member state is based on the share of such fuels in the year 2020. The cap is defined as one percent point higher that that 2020 level (with 7% as absolute maximum).[11]
- Where that share in 2020 is below 1% in a Member State, it may be increased to a maximum of 2% of the final consumption of energy in the road and rail transport sectors.
- Member States may set a lower limit and may distinguish between different biofuels, bioliquids and biomass fuels produced from food and feed crops, taking into account best available evidence on indirect land-use change impact. Member States may, for example, set a lower limit for the share of biofuels, bioliquids and biomass fuels produced from oil crops.

The resulting cap for food and feed crop based biofuels a Member State has set, can impact the overall minimum share for renewable energy in transport. As mentioned above, the minimum share is set at 14%. If a Member State has limited biofuels based on food and feed crops to a share lower than 7% or a Member State has decided to

[11] As an illustration: in case of a share of 3,5% in the year 2020, the resulting cap becomes 4,5%; in case the share is 6,5% in 2020, the resulting cap becomes 7%.

limit the share further, that Member State may reduce the minimum share, by a maximum of 7 percentage points.

Special conditions for biofuels from high iluc-feedstocks

The Directive aims at reducing and phasing out the share of biofuels from feedstocks with high risks for indirect land use change (iluc). Following a delegated regulation published 13 March 2019[12] palm oil currently is the only feedstock characterised as high-iluc risk feedstock. Member States can only incorporate biofuels from such feedstock in the calculation of the share of renewable energy in transport up to the level of consumption of such fuel in that Member State in 2019, unless they are certified to be low indirect land-use change- risk biofuels. From 31 December 2023 until 31 December 2030 at the latest, that limit shall gradually decrease to 0%. The Directive has not prescribed a specific trajectory for this decrease.

Calculation rules with regard to the minimum shares of renewable energy in the transport sector (Article 27)

Full details on the calculation of the minimum shares of renewable energy can be found in Article 27 of RED2. For biofuels from feedstocks mentioned in Part B of Annex IX (used cooking oil, animal fats) the following is important:

- the share of biofuels and biogas produced from the feedstock listed in Part B of Annex IX shall, except for in Cyprus and Malta, be limited to 1.7% of the energy content of transport fuels supplied for consumption or use on the market. Member States may, where justified, modify that limit, taking into account the availability of feedstock. Any such modification shall be subject to approval by the Commission.

For the compliance of the minimum share, the share of some biofuels may be subject to a multiplier factor:

- the share of biofuels and biogas for transport produced from the feedstock listed in Annex IX may be considered to be twice its energy content;
- the share of renewable electricity shall be considered to be four times its energy content when supplied to road vehicles and may be considered to be 1.5 times its energy content when supplied to rail transport;
- with the exception of fuels produced from food and feed crops, the share of fuels supplied in the aviation and maritime sectors shall be considered to be 1.2 times their energy content.

Sustainability and greenhouse gas emissions saving criteria for biofuels, bioliquids and biomass fuels (Article 29)

Member States can only take the energy from biofuels, bioliquids and biomass fuels into account if they fulfil the sustainability and the greenhouse gas emissions saving criteria described in the directive.

Special conditions apply for biofuels, bioliquids and biomass fuels produced from waste and residues, other than agricultural, aquaculture, fisheries and forestry

[12] See https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=PI_COM:C(2019)2055&from=EN

residues. They are required to fulfil only the greenhouse gas emissions saving criteria laid down in paragraph 10 of article 29 in order to be taken into account.

The sustainability and the greenhouse gas emissions saving criteria shall apply irrespective of the geographical origin of the biomass.

Biofuels produced from agricultural biomass shall not be made from raw material obtained from land with a high biodiversity value, with high-carbon stock or land that was peatland in January 2008. In the paragraphs of Article 29 it is further clarified which type of lands are meant.

For biofuels produced from forest biomass also a list of criteria is mentioned in Article 29 to minimise the risk of using forest biomass derived from unsustainable production.

The greenhouse gas emission savings from the use of biofuels shall be:

- at least 50% for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations in operation on or before 5 October 2015;
- at least 60% for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations starting operation from 6 October 2015 until 31 December 2020;
- at least 65% for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations starting operation from 1 January 2021;
- at least 70% for electricity, heating and cooling production from biomass fuels used in installations starting operation from 1 January 2021 until 31 December 2025, and 80% for installations starting operation from 1 January 2026.

The greenhouse gas emissions savings from the use of renewable liquid and gaseous transport fuels of non- biological origin shall be at least 70% from 1 January 2021 (Article 25).

A new fuel category is introduced: Recycled Carbon Fuels

One of the remarkable new categories in the new Renewable Energy Directive is the inclusion of the option to Member States to account the contribution of Recycled Carbon Fuels to the Renewable energy target in transport. Recycled Carbon Fuels are e.g. fuels produced from industrial waste gases or based on non-recyclable plastics. As such they are not from renewable origin – at least not as long as these industrial waste gases and plastic resources are currently predominantly based on fossil resources. The argument to include them may be that by using fuels from these waste streams virgin fossil fuels are avoided.

Member States are given the option to include these fuels in their national obligation to fuel suppliers (Article 25-1(b)).

The European Commission shall adopt a delegated act – no later than 1 January 2021 - to supplement the Directive by establishing appropriate minimum thresholds for greenhouse gas emissions savings of recycled carbon fuels through a life-cycle assessment that takes into account the specificities of each fuel.

3 Greenhouse gas saving issues

3.1 Key ‘take aways’

Centrale take-away messages are:

- The concept of Greenhouse gas savings within the EU Directives is rather technical. In principle, it is an instrument to determine whether a biofuel performs better than a certain threshold level. Only than the biofuel is regarded as a sustainable biofuel contributing to the obligation for renewable energy in transport. The performance of various biofuels is compared to a standard fossil fuel comparator with the purpose of checking whether a threshold level is reached. The fossil fuel comparator in the first RED and RED 2 differ in value;
- Different terminologies are used:
  - Default values, which are numbers provided in the directives to be used, without further evidence provision requirements;
  - Typical values, which are values the Joint Research Centre of the European Commission has determined as the typical values to expect from current operations and technologies for such pathways;
  - Actual values: calculated values, following methodologies from EU approved certification schemes to calculate the emissions in the different stages of the production pathway;
- Fossil fuel comparator for biofuels and biogas in transport: the value the EU has set to compare performance against. In RED 1 the value is 83.8 gCO_{2eq}/MJ, in RED 2 the value will be 94 gCO_{2eq}/MJ;
- Threshold levels for greenhouse gas saving of biofuels: at the start of the RED in 2009, the threshold level was 35%. Over time it has increased to 50% and 60% and will also further increase in the RED2 for new plants coming in operation (65%);
- The increased values will mean that all players in the sector have to innovate to find efficiency gains in their production pathways;
- It also will mean that those pathways with very low typical values and corresponding default values will face difficulties surpassing the threshold levels;
- The focus will become more and more on waste based biofuels and as a result on new conversion technologies.

3.2 Introduction

Since the Renewable Energy Directive published in 2009 biofuels can only contribute to the obligation and to the overall share of renewables in the total final energy consumption if they comply to the sustainability criteria. One of the most relevant issues in these criteria is the threshold value for greenhouse gas savings, compared to the fossil alternative.

In the next sections this will be elaborated briefly for:

- The existing RED, which is in place until the end of 2020;
- The new RED2, which will be transposed to national laws for the period 2021-2030.

Furthermore, it is necessary to distinguish between the various types of renewable fuels that are allowed as contributors to the obligation of renewable energy for transport:

- Biofuels;
- Renewable fuels of non-biological origin;
- Recycled carbon fuels (only in RED2).

Renewable electricity is not subject to a greenhouse gas savings threshold.

GHG savings in the existing RED

The general situation, valid for biofuels

In Consideration 16 of the 2015 Directive[13] amending the 2009 RED the following is stated: "The minimum greenhouse gas emission savings threshold for biofuels and bioliquids produced in new installations should be increased in order to improve their overall greenhouse gas balance as well as to discourage further investments in installations with a low greenhouse gas emission savings performance. This increase provides investment safeguards for biofuels and bioliquids production capacities in conformity with the second subparagraph of Article 19(6) of Directive 2009/28/EC."

The following thresholds are currently in place for the greenhouse gas savings of biofuels:

- at least 60% for biofuels produced in installations starting operation after 5 October 2015[14];
- at least 50% for biofuels produced in installations that were in operation on or before 5 October 2015.

The greenhouse gas savings calculations method is mentioned in Article 19 of the RED and in detail the methodology is provided in section C of Annex V of the Directive. The Directive provides two different sets of data, which will be discussed later this section:

1. the greenhouse gas saving as a percentage, compared to the fossil fuel comparator[15];
2. the greenhouse gas emissions in gCO_{2eq}/MJ.

The greenhouse gas emissions of the biofuels production chain consist of three segments of the production chain:

- for cultivation (in the case of wastes and residues the greenhouse gas emission value is 0);
- for processing (the actual production of the biofuel in a conversion facility);
- transport and distribution.

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[13] See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015L1513

[14] An installation shall be considered to be in operation if the physical production of biofuels has taken place.

[15] In point 19 of section C of Annex V the following is described: "*For biofuels, for the purposes of the calculation referred to in point 4, the fossil fuel comparator EF shall be the latest available actual average emissions from the fossil part of petrol and diesel consumed in the Community as reported under Directive 98/70/EC. If no such data are available, the value used shall be 83,8 gCO_{2eq}/MJ.*"

In general it can be stated that for annual agricultural crops the share of the greenhouse gas emissions in the cultivation stage are highest compared to the other two segments.

Obligated parties have three options to determine the calculation option:

- Using a **default value**[16] for those biofuel pathways that are mentioned in the RED's Annex V, section A (existing biofuel pathways) and section B for so-called 'future biofuels', i.e. "*biofuels that were not on the market or were on the market only in negligible quantities in January 2008*".
- Using an **actual value,** calculated in accordance with the methodology laid down in part C of Annex V, o
- Using a **combined value**, based on either the default value or actual (thus calculated) value for each of the three segments of the production chain mention above.

The commission introduced the division between default and actual values to minimise the administrative burden for obligated parties. Default values can be used, but at the 'cost' of being a more conservative value than the typical values a particular biofuel pathway could realise. In reality it turned out that as long as default value of a biofuel pathway was above the threshold level and higher actual greenhouse gas saving were not awarded, involved parties preferred to use default values on the Proofs of sustainability that accompanied biofuels throughout the supply chain. Up to end of 2017 the threshold level for greenhouse gas savings was as low as 35%, and the default values of most biofuel pathways complied. With the threshold of 50% several biofuel pathways have lower default values, which will cause either a shift to biofuels produced from other feedstocks, or innovative actions need to be undertaken to reduce the energy input or other inputs in the value chain, and demonstrate these improvements with actual value calculations.

In Figure 5 an overview is given of the greenhouse gas savings (compared to the fossil fuel comparator of 83.8 gCO_{2eq}/MJ) of biofuel pathways mentioned in Annex V of the 2009-Directive. Conventional, food and feed crop based biofuels are shown in orange, Annex IX-B wastes in light blue and waste-based advanced biofuels (Annex IX-A) in blue. The left-end side of the horizontal bars indicate the default value, the right end side the typical values. The graph does not show the actual values as these are case specific.

When Germany introduced a new compliance system, based on reducing the average CO_{2eq}-intensity of the total fuel mix provided to the German road transport market, rather than on the share of renewable energy, the approach on which GHG-saving value to use changed. The 2015 target of 3.5% less CO_{2eq}-intensity of the total fuel mix led to improvements in the agricultural practices in the cultivation, as a means to improve the overall GHG-saving of e.g. rapeseed biodiesel and actual values of around 55-60% where reported and verified, as compared to the default

[16] Default value is defined in the RED as: a value derived from a typical value by the application of pre-determined factors and that may, in circumstances specified in this Directive, be used in place of an actual value. A typical value is defined as: an estimate of the representative greenhouse gas emission saving for a particular biofuel production pathway.

value of 38% as mentioned in the Directive. Due to these improvements, the options remained compliant to the Directives sustainability criteria.

The situation for renewable fuels of non-biological origin (RFNBO)

As stated in the previous chapter, renewable liquid and gaseous fuels of non-biological origin where introduced as a new category of fuels to fulfil the renewable energy in transport obligation. These fuels are based on renewable electricity, which is connected carbon molecule, captured from the air or from gases with high concentration of CO_2 (like available at ethanol-plants).

Only in the RED2, so from 2021 onwards, a threshold value for RFNBOs will be applied.

GHG savings in the upcoming RED2

The general situation, valid for biofuels

Several items have changed in the RED2, valid for the period 2021-2030, as compared to the current active Renewable energy directive.

- A new threshold value is introduced, next to those already active (see section "GHG savings in the existing RED":
  the greenhouse gas saving needs to be at least 70% for biofuels produced in plants first in operation after 1st January 2021.
- For much more biofuel pathways default and typical values are mentioned, with specific details about the (type of energy used in the production processes) in Annex V for liquid biofuels and Annex VI for biomethane for transport[17].

[17] Annex 6 contains a large number of tables with greenhouse gas information about biomass for electricity and heat. Only one specific table provides details on biomethane for transport purposes.

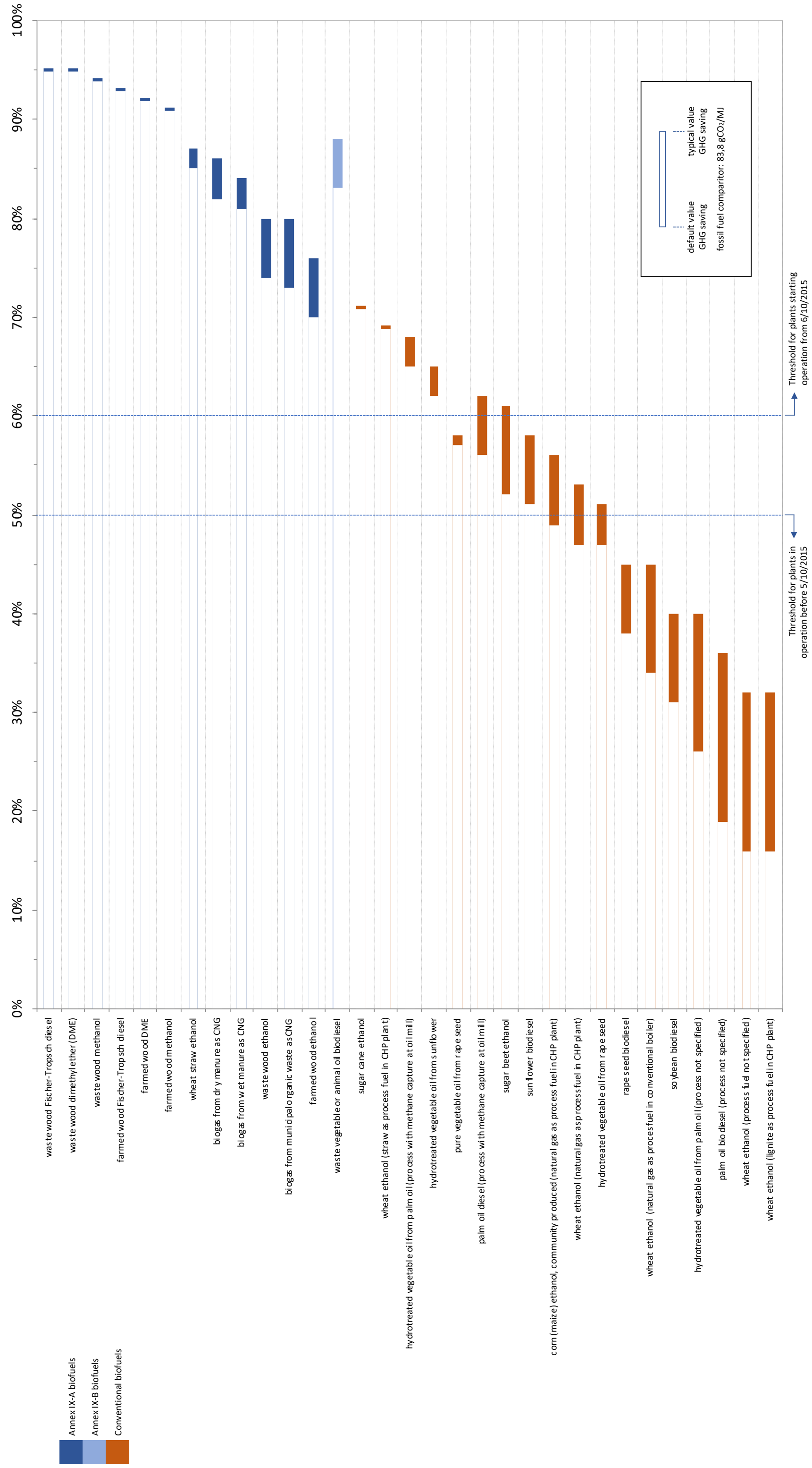

Figure 5 Default and typical values of biofuel pathways in the 2009-RED

- The fossil fuel comparator for transport has changed from 83.8 gCO_{2eq}/MJ in the current RED tot 94 gCO_{2eq}/MJ in RED2.
  This is important to be aware of, because of the following. CO_2-intensity information of various biofuels are to be seen as absolute number and may depend on the type of energy used in the cultivation of the conversion processes. The GHG savings percentages are always relative and need to be seen in respect to the right comparator. An example: the threshold value of at least 60% in the current RED and the same threshold value in RED 2 result in different CO_2-intensity values for a fuel to comply. At least 60% reduction under 83.8 gCO_{2eq}/MJ of the current RED would mean that any biofuel would work with CO_2-intensity of less than 33.5 gCO_{2eq}/MJ, whereas under the RED2 a CO_2-intensity of less than 37.6 gCO_{2eq}/MJ would be sufficient.

Details on the various pathways in provided in Figure 6. It is interesting to see how the inclusion of biomethane options has shifted to overall picture. Utilisation of these biofuels would result to very high GHG-saving, due to avoided methane emissions.

The situation for renewable fuels of non-biological origin (RFNBO)

RED2 has introduced GHG-threshold value for renewable liquid and gaseous fuels of non-biological origin: From 1 January 2021 onwards the GHG saving should be at least 70%.

The situation for Recycled Carbon Fuels (RCF)

In the previous chapter it was explained that in the RED2 the possibility was provided for Member States to take the contribution of Recycled Carbon Fuels (RCF) into account for the renewable energy in transport obligation.

By 1 January 2021, the European Commission will adopt a delegated act, to supplement the RED2-Directive, about the threshold values for the GHG-saving of recycles carbon fuels, based on a life cycle analysis, taking into account the specific characteristics of each fuels under this category.

By 31 December 2021, the Commission shall adopt a delegated act to supplement this Directive by specifying the methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels, which shall ensure that credit for avoided emissions is not given for CO2 the capture of which has already received an emission credit under other provisions of law.

The situation for co-processed biofuels

Another specific type of biofuel for which a delegated act will be prepared, also by 31 December 2021 at the latest, relates to biofuels that are being produced via so called co-processing with fossil fuels in a common process, such as a conventional refinery, by specifying the methodology to determine the share of biofuel, and biogas for transport, resulting from biomass being processed with fossil fuels in a common process.

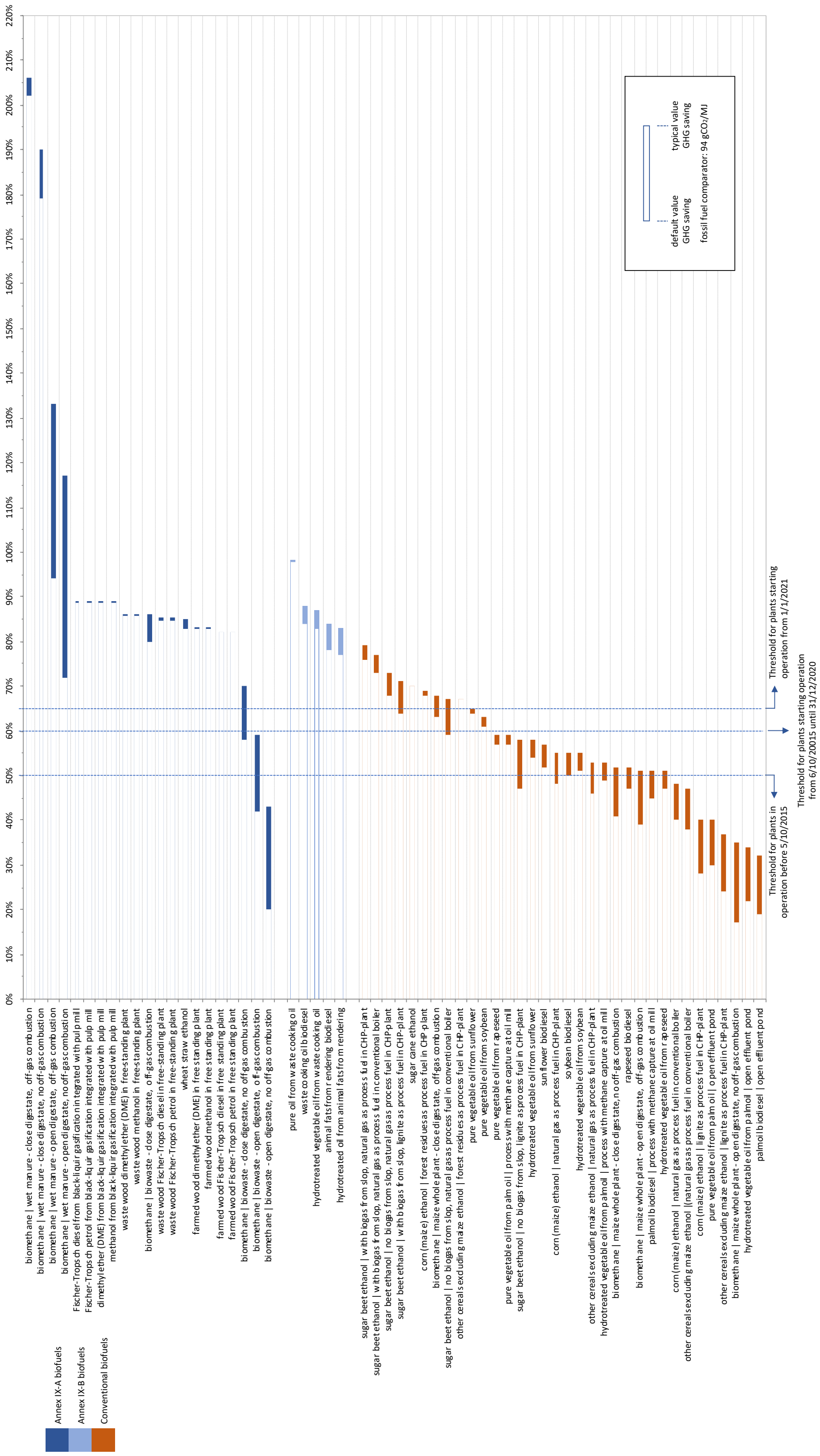

Figure 6 Default and typical values of biofuel pathways in the RED2 for 2021-2030.

4 Insights in production costs

4.1 Key 'take aways'

- Information on production costs of biofuels is only limited available
- Feedstock costs are most determining production costs
- New technologies for processing Annex IX-A feedstocks (waste and residues) are facing more complex technologies and thus increased capital costs.
- Price information on traded volumes are available for the most traded biofuels, like FAME, HVO and ethanol, but reflect market prices, not necessarily productions costs

4.2 Introduction

Information on production costs of biofuels is only limited available. At conferences and other public events significant information is provided on the technological details and developments. Questions on prices and costs, however, are mostly not answered, for commercial reasons. From a legal perspective point of view industrial parties are held to the competition law rules and may not disclose financial information, or only under strict conditions.[18]

Nevertheless, general information is available in some public reports on costs of biofuels production. In this paper, information from the Sub Group on Advanced Biofuels, which was installed under the Sustainable Transport Forum by the EC[19] and was active from 2016 to end of 2017, is used to provide some insights on productions costs. Another potential source of information for market prices – not production costs – for biofuels that are currently traded globally and at European level is the F.O. Licht data services, or the Platts biofuel data services. Based on information from daily traded biofuels, both organisations provide insights in the cif- and fob-prices of most common biofuels traded, especially ethanol and biodiesel (FAME and UCO).[20] However, price information on new and upcoming fuels, like advanced biofuels, electrofuels or recycled carbon fuels, is not available as these prices are determined directly and discretely between supplier and customer.

In order to understand information on the production costs it is also important to acknowledge the development status of specific conversion technologies. As was illustrated in the chapter 1, various conversion technologies, especially those based on conventional agricultural products, are commercially mature, whereas other technologies, like lignocellulosic based ethanol, are about the enter the market, or are still in a more juvenile stage of development. In the latter case mentioned production costs are to be viewed as estimates, where information of commercial plants reflects realised production cost information. This is illustrated in Figure 7.

[18] See: https://europa.eu/youreurope/business/selling-in-eu/competition-between-businesses/competition-rules-eu/index_en.htm
[19] See: https://ec.europa.eu/transport/themes/urban/cpt/stf_en
[20] See: https://www.spglobal.com/platts/en/commodities/agriculture/biofuels and https://www.agra-net.com/agra/world-ethanol-and-biofuels-report/

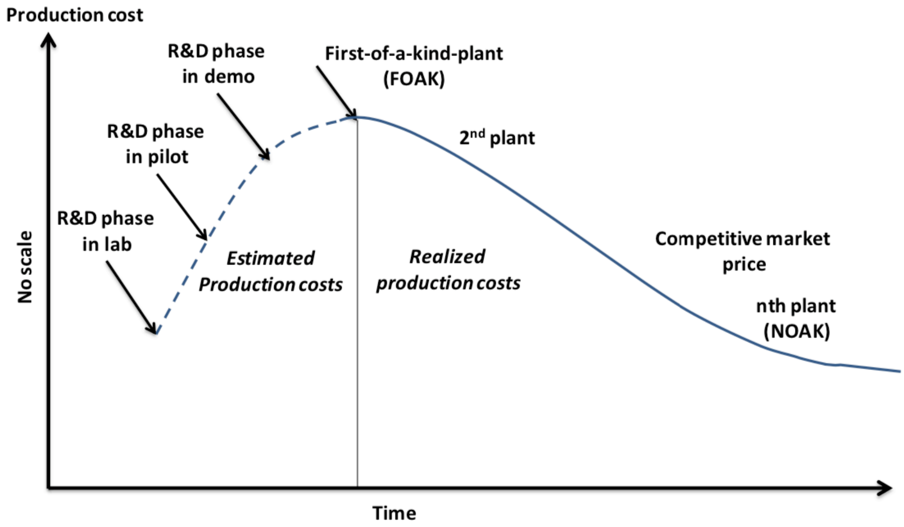

Figure 7 'Learning effect': development of production costs from innovation stage to commercial stage (Landälv, Waldheim, 2018)

Most advanced biofuel production pathways are in the innovation phase. The industry, while acting on innovation for quite some time, but only now that more clarity is achieved in the RED2 on sub-target, just starting their path to commercialisation

4.3 Feedstock costs dominate production costs

One key characteristic of the biofuels pathways, in comparison to e.g. renewable energy from wind and solar sources, is that the source, the feedstock does not come at a free cost. In fact "the cost of biofuels is mainly governed by the cost of the resource (feedstock) and the cost of capital (the investment) and only value chains based on waste streams with zero or negative cost offer possibilities for competitive cost production at present", according to Landälv and Waldheim in the 2017 report.

Furthermore it is emphasised that the capital costs for advanced biofuel are substantially higher than the capital costs of similar conventional production plants. The result is that the relative share of feedstock costs decreased and the share of capital costs increases, but above all the total production costs are to be expected higher.

Biofuels will remain more expense than fossil fuels, unless the costs of mitigating climate change are going to be factored in in the costs of fossil fuels.

4.4 Overview of production costs of advance biofuel production pathways.

Landälv and Waldheim executed an analysis of various advanced biofuel production pathways. none of them are substantial part of the existing biofuels delivered currently to the market. These are pathways that have reached Technology Readiness Levels of 7-9 (see for description of levels Annex A), meaning they are appearing as first-of-a-kind plant at the brink of commercialisation. These technologies, used as fuel for road transport or as a niche product for the aviation sector, are:

- Oxygenates and hydrocarbons from thermochemical processing of lignocellulosic biomass or waste streams;
- Drop-in hydrocarbon fuels form hydrogenation of waste lipids (HVO);
- Oxygenates and hydrocarbons from biochemical processing of lignocellulosic biomass or waste streams; and
- Bio-methane from anaerobic digestion or from gasification of lignocellulosic materials or waste streams.

In Figure 8 the results of their initial analysis are presented in red, after which their analysed data were reviewed and validated by the industries connected to the sub Group Advanced Biofuels, after which Landälv and Waldheim adjusted their findings to the information indicated in green.

On the horizontal axis the various technology pathways are presented, while at the Y-axis the production costs in euro per MegaWatthour (€/MWh)[21] are presented.

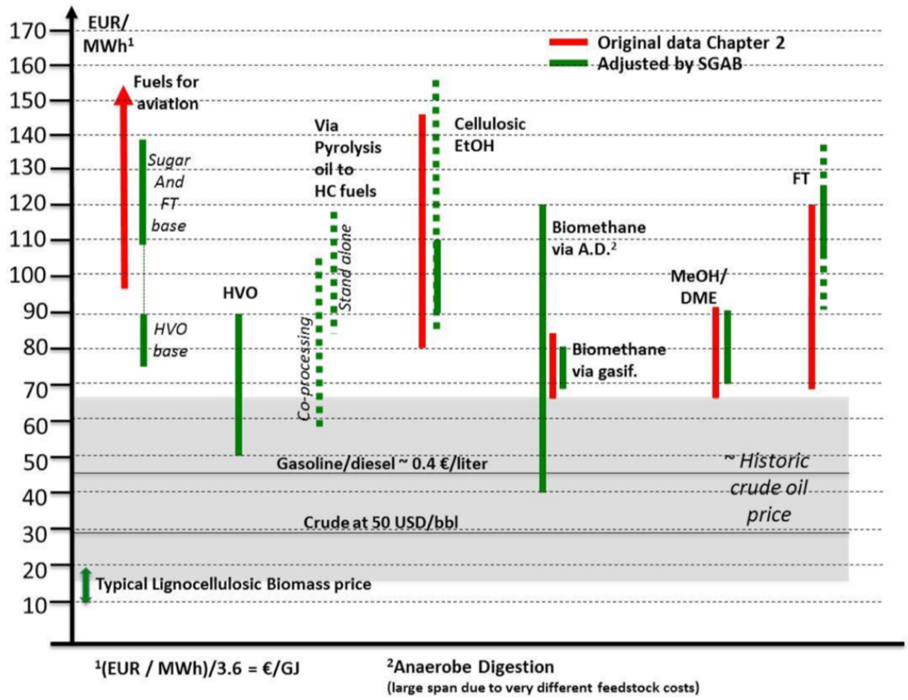

Figure 8 Summary of production costs for various pathways (Landälv, Waldheim, 2017) [clarification of abbreviations: A.D.: anaerobic digestion; DME: dimethylether, a gas based diesel alternative, EtOH: ethanol; EUR: euro; FT: Fischer-Tropsch process; HC: hydrocarbon; MeOH: methanol, MWh: MegaWatthour; USD: US Dollar]

In order to convert these production into euro's per m^3 of fuel, it is necessary to include also the energy content of the fuels. In the next table, based on the data of Landälv and Waldheim, these production costs per volume of fuel are presented (see that two right hand side columns). It must be noted that when comparing the price

[21] Conversion factor: (€/Mwh)/3.6 = €/GJ. So as an example from the graph: production cost of HVO varies between 50 and 90 €/MWh, equaling 13,9 – 25 €/GJ. The energy content of HVO is 34 GJ/m^3. Thus this production cost equals 473 – 850 €/m^3

per m^3 it remains necessary to include the differences of energy content of the various fuels.

From Figure 8 it can be concluded that biomethane, and to a lesser extent, HVO, are closest to closing the gap with conventional gasoline and diesel. Other options would require either an incentive to lower the costs for the biofuels or the addition of a carbon fee on the fossil alternatives to reach price parity.

Table 2 Overview of biofuel production costs (Landälv, Waldheim, 2017) [last two columns added by sGU]

Biofuel type production costs	**Feedstock price (€/MWh)**	**Production cost range (€/MWh)**	**Production cost range (€/GJ)**	**Energy content (GJ/m^3)**	**Production cost range (€/m^3)**
Aviation:					
• Biofuel to jet (Hydrotreated Esters and Fatty Acids, HEFA)	40-60	80-90	22-25	42	924-1,050
• Sugar fermentation (Alcohol-to-jet, ATJ) or Fischer-Tropsch (FT) synthesis	Sugar: 65-85 FT: 10-20	110-140	31-39	42	1,302-1,638
HVO liquids	40 60	50-70 70-90	14-19 19-25	34	476-646 646-850
Biomethane from biogas	0-80	40-120	11-34	50 GJ/ton	550-1,700 €/ton
Cellulosic ethanol	13 10	103 85	29 24	21	609 504
Biomethane & ethanol from waste		67-87	19-24	21[a)]	399-504
FT liquids from wood	20 10-15	105-139 90-105	29-35 25-29	36	1,055-1,260 900-1,055
Biomethane, methanol or DME (dimethylether) from wood	20 20-25	71-91 56-75	20-25 16-21	19[b)]	380-475 304-399
Pyrolysis bio-oil co-processing	10-20	58-104	14-27	34[c)]	476-918
Pyrolysis bio-oil stand alone	10-20	83-118	23-33	34[c)]	782-1,122

a) energy content used based on ethanol
b) energy content used based on methanol
c) Assumption by sGU for this report that the energy content of the converted pyrolysis oil is equal to that of HVO

One important instrument now in place to overcome this hurdle is the sub-target for advanced biofuels, which will reach a share of at least 3.5% of the total market (though this includes double counting, so on physical base it would equal a 1.75% share). Based on discussions within the ART Fuels Forum a rough estimate was that this would equal a total capital investment of 13-20 billion euros, to erect plants to provide this amount of advanced biofuels to the market.[22]

[22] Personal communication within ART Fuels Forum meeting, 2019.

5 Potential volumes and market share between now and 2050

5.1 Key "take-away" messages

- From the EU 2016 reference studies it must be concluded that for 2030 and for 2050 still significant shares of conventional fuels are to be expected.
- The way the RED2 (with targets for 2030) allows the use of multipliers and double counting, the actual, physical share of electricity and biofuels will remain rather limited, and as a result, the share of renewable energy will not grow ads may be expected from the RED2 mandates for renewable energy. 2% electricity and 6% biofuels share in 2030 transport sector would result in an administrative share of nearly 20% in 2030, while in actual terms it would only be 8%.
- Given the fact that the European Union also has ambitions to reduce the emissions of greenhouse gases, to a level of at least 40% below the level of 1990, this report concluded that the RED2 will result in a CO_2-gap. By achieving the RED2 targets in 2030 the EU would fall short in achieving this target. In fact 2.6% more physical share of renewable energy would be needed, corresponding to about 29% of renewable energy (factual, not administrative, so without any double counting or use of multipliers)
- Also in 2030 the dominant energy carrier in transport in EU28 will be liquid fuels, even though the market introduction of electric mobility shows stark growth. Next to biofuels, other renewable fuels, like electrofuels, will be needed. But also the expansion of electricity mobility accompanied with increased availability of renewable electricity will be required to improve the GHG-performance of the transport sector.

5.2 Introduction

In 2016, the European Commission published the "EU Reference Scenario 2016 - Energy, transport and GHG emissions Trends to 2050" report.[23] The report is an update of the 2013 Reference Scenario. It focuses on the EU energy system, transport and greenhouse gas (GHG) emission developments, including specific sections on emission trends not related to energy, and on the various interactions among policies in these sectors. Its time horizon is up to 2050 and it includes all EU28 Member States. The Reference Scenario acts as a benchmark of the policy and market trends at the time of publication. As such, it aims to inform future policy debate and policy making, though it does not include a target driven approach on how to achieve such target. E.g. the report did not include the implications of the Paris Agreement.

The information provided on the transport sector is relevant in the light of the published RED2-targets and also in light with perspectives sketched by international organisations such as the International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA).

In the following sections the information from these bodies are presented and discussed. Some examples of approached of a few Member States will be provided.

[23] See: https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

5.3 The EU reference Scenario 2016

As stated, the EU Reference Scenario study is based on various models used by the European Commission and presents projections, not forecasts. For a thorough understanding of all assumptions and concepts used the reader is referred to chapter 2 of the report on framework conditions and inputs to the model.

In this paper the outcomes of the report will be discussed, with a focus on the results for the transport sector.

Figure 9 present the projections for the final energy consumption by fuel and by sector for all EU Member States.

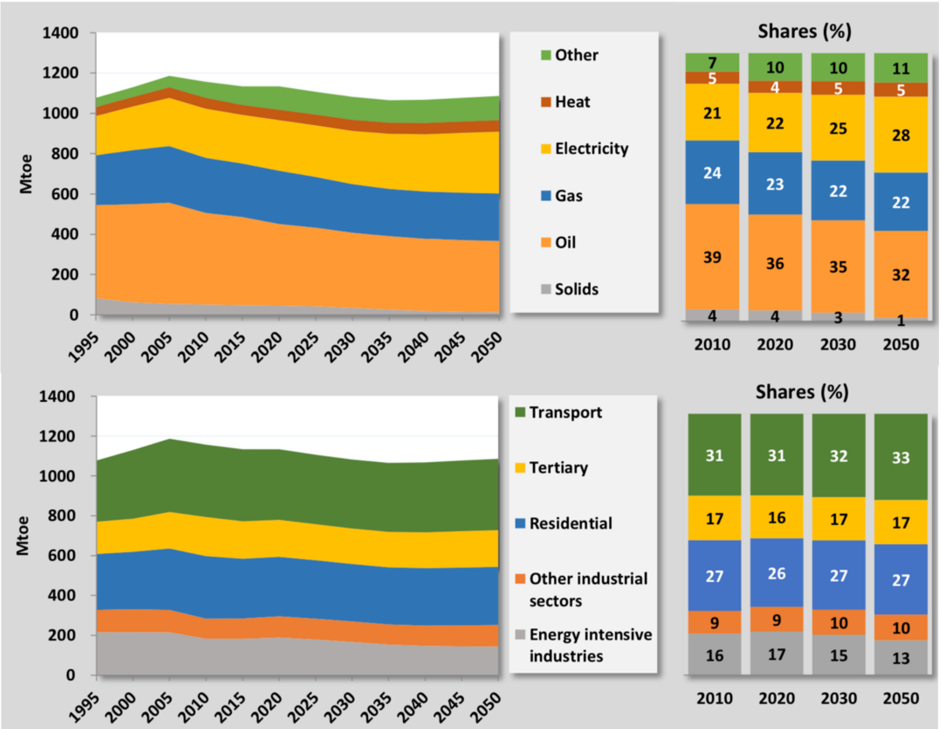

Figure 9 Final energy consumption by fuel and by sector (EC, 2016)

Form the graphs it can be seen that, based on the policies in place the final energy consumption is projected to be stable up to 2050 (at approx. 1,100 Mtoe[24]. Also final consumption in the transport sector seems to remain stable around 350 Mtoe (14,650PJ). The report clarifies that while energy efficiency continues to further improve this is outbalanced by the growth of GDP, requiring more energy. The result seems a stabilization.

Diving into the transport trends, the report sees ongoing increase in the amount of passenger kilometres (in all type of modes, but particularly in passenger cars), as well as an increase in freight transport, as can be seen from Figure 10 and Figure 11.

[24] 1,100 Mtoe equals 46 ExaJoule (EJ), or 46,055 PetaJoule (PJ). Conversion factor: 1 Mtoe = 41.87 PJ

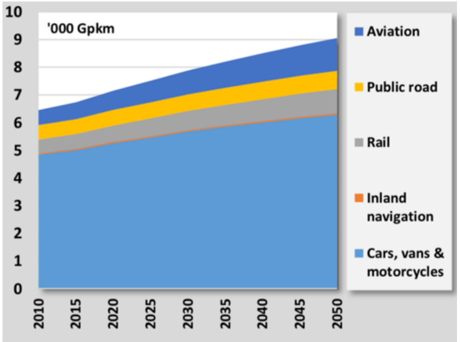

Figure 10 Passenger transport activity by mode

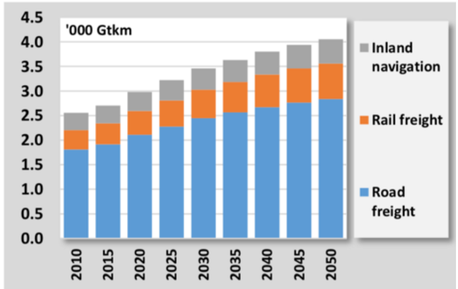

Figure 11 Freight transport activity by mode

One would expect growth in energy consumption in transport when viewing such growth in mobility trends. Again, based on expectation of energy efficiency improvements, the trends look different as can be seen from Figure 12.

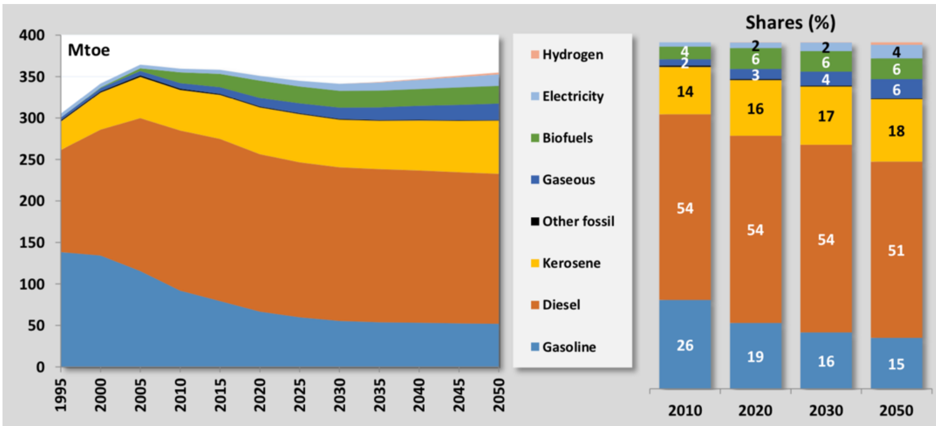

Figure 12 Final energy demand by fuel type

The report estimated that 2050 final energy consumption will be nearly at the same level as in 2005: around approx. 350 Mtoe (14,650 PJ). Most surprising – with the knowledge of the RED2-plans and the signed Paris Agreement - is the low expected share of hydrogen, electricity and biofuels, respectively <1%, 4% and 6% in 2050.

The forecast in this reference scenario for the energy use in the various transport segments is presented in Figure 13. It can be seen that of the 350 Mtoe (14,650 PJ) total final energy demand about approx. 275 Mtoe (11,515 PJ will be used on road transport, whereas rail will be rounded max 5 Mtoe (210 PJ), aviation (being only intra-EU aviation) will be around 70 Mtoe (2,930 PJ) and inland shipping only up to 3 Mtoe (125 PJ). Please note that international shipping and aviation are not included in this overview.

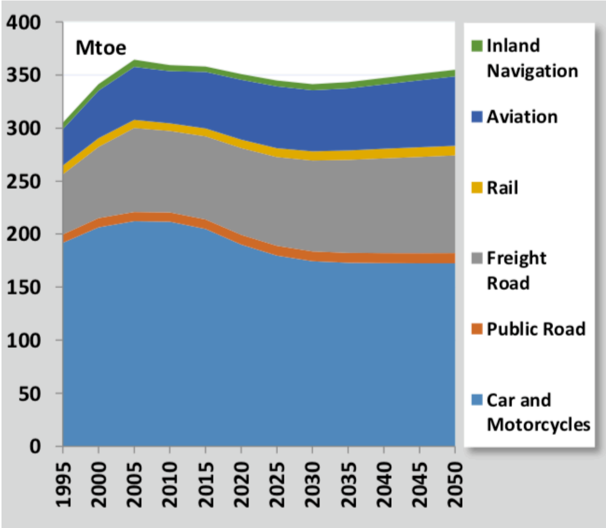

Figure 13 Final energy demand in the transport segments

As a thought experiment, let's assume for the situation in 2030:

- that the fuel type numbers mentioned in Figure 12 are as follows divided over the segments:
  - electricity will only enter into road transport (and assuming that in 2030 80% of all electricity is renewable based)
  - every transport segment has an equal physical share of biofuels
- and that the multipliers for electricity (factor 4) and for use in shipping and aviation (factor 1.2) are to be applied
- at least 3.5% (double counted, so physically 1.75%) advanced fuels need to be applied. This percentage is related to the road and rail volumes (275+5= 280 Mtoe): 1.75% *280 Mtoe = 5 Mtoe (210 PJ).
- Max 1.7% of Annex-IX-B biofuels are allowed: 1.75%*280 = 5 Mtoe (210 PJ)

What would this result in in 2030, in order to comply to the RED2 target of at least 14%, which is based on the share of the sum of road and rail?

From Figure 12 it can be seen that in 2030 the share of electricity is 2% (of total 350 Mtoe), equal to 7 Mtoe. With the multiplier this means that it should count as 8% (of 350 Mtoe), equalling 28 Mtoe (1,175 PJ). Correcting for an (assumed) renewable share of electricity of 80% this results in 6,4% and 22,4 Mtoe (940 PJ). This represents a share of 8% or road and rail).

Biofuels contribute 6% of total energy consumption in transport (see Figure 12), which equals 21 Mtoe (6%*350 Mtoe, 880 PJ). Besides 5 Mtoe (210 PJ) advanced biofuels and 5 Mtoe annex-IX-B biofuels (210 PJ), 11 Mtoe (460 PJ) conventional biofuels are needed. This equals 3,9% of the total energy consumption in road and rail and thus stays within the cap of 7% for food and feed crop based biofuels.

Equal division of the biofuels over the transport segments would mean:

- 16.6 Mtoe biofuels used in road transport, of which 5 Mtoe is advanced biofuels (Annex IX-A) and the Annex IX-B may be double counted – which is assumed here to occur, in total: 21.6 Mtoe (905 PJ)
- 4.2 Mtoe used in aviation, which has to be multiplied with 1.2, can contribute to the RED2-obilgation as 5.0 Mtoe (210 PJ)

- 0.2 Mtoe used in inland shipping, which has to be multiplied with 1.2, can contribute to the RED2-obilgation as 0.3 Mtoe (15 PJ)
- Total physical volume is 21 Mtoe (880 PJ). For the RED2-obligation it adds up to 32,3 Mtoe (1,345 PJ).

So while in reality 8% of the total energy consumption in EU transport is based on electricity (2%) and biofuels (6%), totalling to 28 Mtoe (1,175 PJ), for RED2 can be reported that 22.4+32.3=54.7 Mtoe (2,290 PJ) renewable energy in transport is provided, equalling a 20% share of total energy consumption in road and rail.

In summary this is represented in Figure 14. On the left hand side, for the years 2009-2017 information is provided for the actual consumption of biofuels in EU28 MS (based on Eurobserv'er annual reports), on the right hand sight the information is provided for the physical and administrative contribution of renewable electricity and fuels in 2030, based on the energy information of the EU reference scenario.

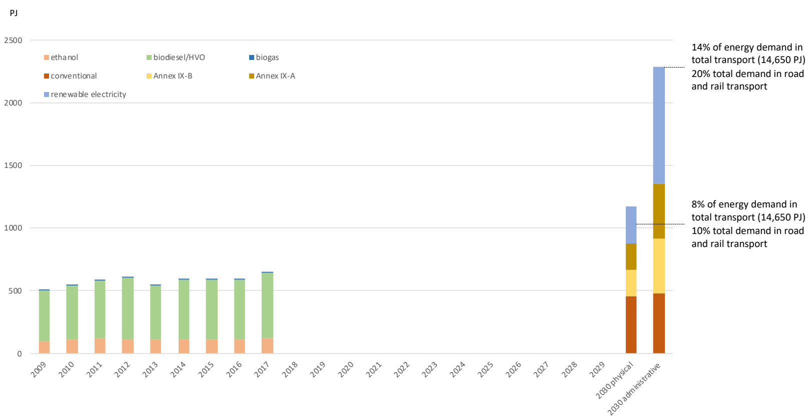

Figure 15 Biofuel consumption in transport (2009-2017) and estimated contribution in 2030 (sGU calculations) on basis of EU reference scenario 2030 (Eurobserv'er reports, 2011:2018, EC, 2016)

This would indicate that the RED2 obligation could easily be met, but not resulting to an actual high share of renewable energy in transport. Given that the transport sector is the only sector that currently is facing increased CO_2-emissions (see Figure 16), it is clear that RED2 may not bring the right impulse to curb this trend.

Where Figure 12 shows that the EU reference scenario does not foresee much further growth towards 2050, except for a further doubling of the share of electricity, it is clear that much more need to be done to reduce the share of fossil fuels used in transport and the bring down carbon emissions from these resources. The international energy agency carried out an analysis on how to approach this. See next section.

5.4 The IEA Technology Roadmap for delivering sustainable bioenergy

In 2017 the International Energy Agency executed an analysis how bioenergy can contribute in achieving a 2°C scenario, in which the global air temperature rise will remain below 2°C as compared to pre-industrial levels, as was agreed at the Paris Climate Conference in 2015. While the report deals with all sectors where bioenergy can play a role, the report also discusses the role of bioenergy in transport.

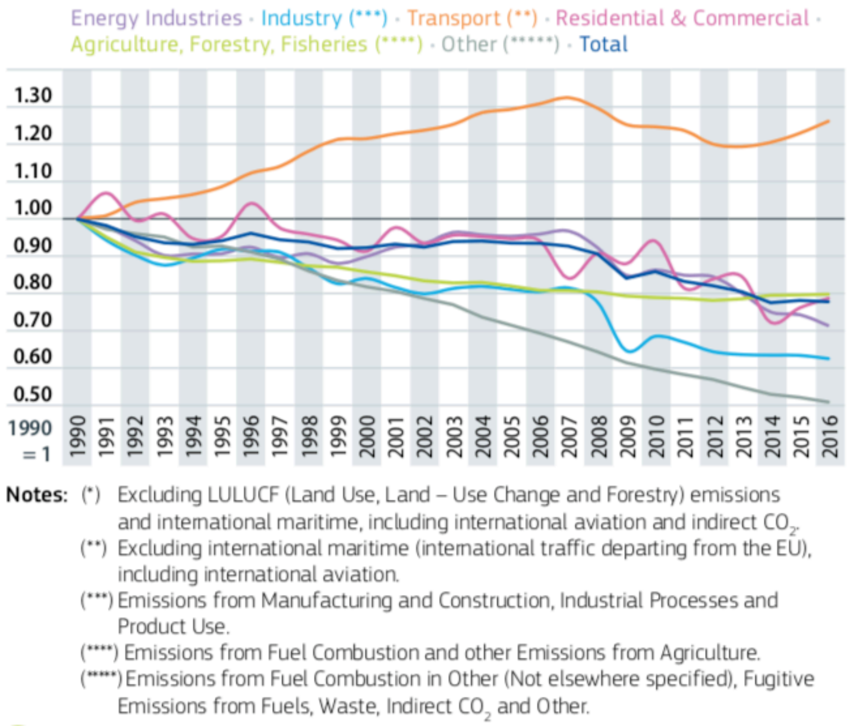

Figure 16 Greenhouse gas emissions EU28 - by sector (EC, 2018b)

Figure 17 shows how in the last decade the share of biofuels in world road transport has increased and in which regions in the period 2010-2016 most of the production growth took place. From the graphs can be seen that Europe is not leading the developments: USA and Brazil are the largest producers and Europe is also the region with the least production expansion.

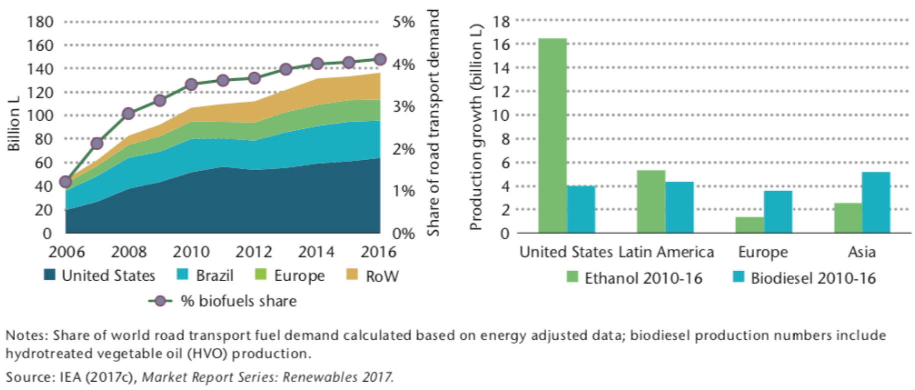

Figure 17 Global biofuel production and share of world road transport fuel demand, 2006-2016 (left), and ethanol and biodiesel production growth for key regions, 2010-16 (right)

In its standard roadmap report the IEA takes as reference the Reference Technology Scenario (RTS), which provides a baseline scenario that takes into account existing and planned energy and climate related commitments by countries. In addition to that IEA also calculates a scenario called the 2°C Scenario (2DS) which is consistent with a 50% change of limiting future global average temperature to 2°C by 2100 and represents an inherently challenging and ambitious transformation of the energy sector.

An illustration of the share of bioenergy, in addition to energy efficiency measures and other renewable energy, to reaching the 2°C scenario is provided in Figure 18. It can be seen that in order to bring the global CO_2-emissions from 40 Gt CO_2/yr to the level of 10 Gt CO_2/yr, other than many stakeholders in the European context anticipate, the contribution of bioenergy is rather modest. It will however, on the other hand, mean that the utilisation of bioenergy needs to be increased significantly. In this respect it must be noted that the 2017-IEA study did not yet include the perspectives of renewable electricity base liquid and gaseous fuels.

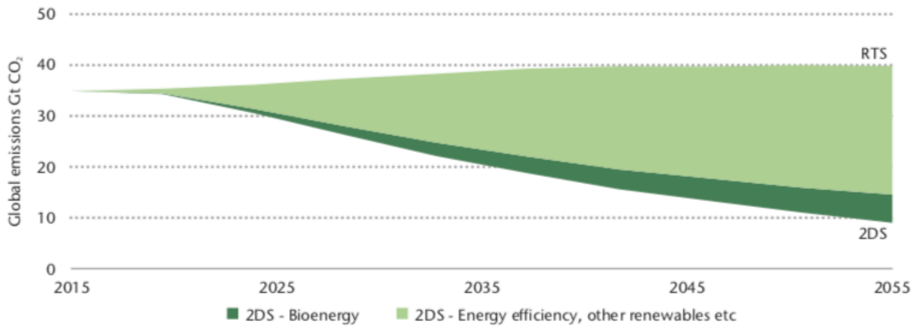

Figure 18 Contribution to emissions reduction in 2DS (IEA, 2017)

Especially in the transport sector the message from the IEA report is very clear:

- when looking forward to 2060 the share of fossil fuel will globally sharply decline,
- there will be a major expansion of the use of bioenergy in the sector, moving up tenfold from today's use of 3 EJ (3,000 PJ) to 30 EJ in 2060, providing 29% of total transport final energy demand
- in addition, electricity use in transport also grows sharply to nearly 27 EJ (26% of total transport final energy demand in 2060)

IEA thus expects that in 2060 both electricity and biofuels will become the dominant energy carriers in the worldwide transport energy demand.

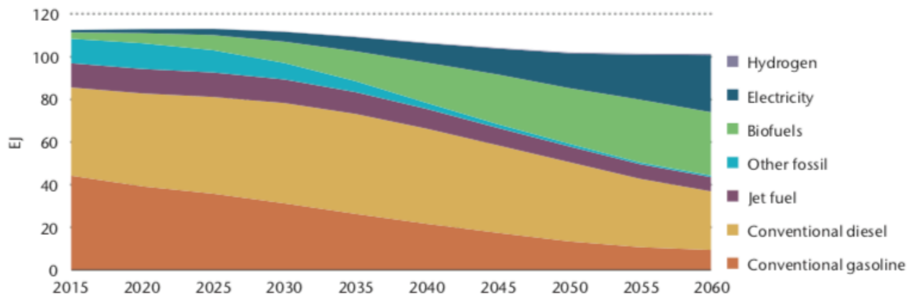

Figure 19 Transport final energy demand in the 2°C scenario (IEA, 2017)

Hydrogen and e-fuels do not appear in these scenario calculations. It might be that these options were at the time of the preparation of the report not sufficiently on the radar. It will remain necessary, therefore, to keep track of future reports from the IEA.

5.5 The CO_2-gap

From the analysis in section 5.2 it becomes clear that the actual, physical shares of renewable energy in the transport sector may not increase sufficiently to contribute to the central issue being the mitigation of greenhouse gas emissions. 8% of renewable energy in total transport by 2030 would equal to at max 8% lower GHG emissions.

In 1990 transport related emissions in EU28 were 793.2 Mton CO_{2eq}[25]. In 2016 they increased to 945.9 Mton CO_{2eq}[26]. From Figure 12 it could be seen that in 2030, but even in 2050, only moderate reductions in the conventional fuel types is to be expected as compared to the 2016 levels.

The European Union aims at a 40% GHG emission reduction target for transport in 2030[27] compare to the 1990 level. Based on this percentage the reduction would equal 317 Mton CO_{2eq}, and still having an emission of 476 Mton CO_{2eq}. How would this compare to the emissions for the numbers for electricity and biofuels (8% in total, equivalent to 1,175 PJ) calculated earlier in this chapter? Based on a tank-to-wheel emission of 74,000 ton CO_{2eq} per PJ of fossil fuel, 1,175 PJ would result in 87 Mton CO_{2eq} less emission reduction, while, as stated above 317 Mton CO_{2eq} emission should be reduced to reach the 40% reduction. The emission reduction should be 2.6 times more than would be achieved by the 8% share, or, in other words, the share of renewable energy in the sector should be 29%, assuming the similar energy consumption. to cover the CO_2-gap.

[25] https://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2019, 1990-data in Table 3.54, page 229

[26] https://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2019, 2015-data in Table 3.54, page 229

[27] See https://ec.europa.eu/clima/policies/transport_en

6 Reflections on synergies and integration

In the previous chapters the perspectives for renewable fuels are discussed.

One of the most obvious conclusions that can be drawn from the information provided is that these that in the decades to come liquid fuels will be needed in transport, and low carbon intensity will be a requisite to get in the direction of keeping world temperature rises close to the levels indicated in the Paris Agreement.

For the use of biofuels in Europe the search for new feedstocks will be key, with corresponding innovation on conversion technologies. The current RED-legislative framework is very clear in this direction. The underlying drivers for this are - in my view - on the one hand food security, and on the other the lack of sufficient direct control and indirect influence with respect to securing sustainable practices for sourcing feedstocks originating from non-European region. To elaborate on the latter issue: within the European context sufficient governance and sustainable management systems are in place for sourcing feedstocks from the agricultural and forestry sector. Monitoring governance in other regions in the world is beyond the power of European bodies – and while the direct supply chain may be well certified, displacement impacts might occur, out of sight.

This implies that a search for new and especially waste-based feedstocks should concentrate on feedstocks within the EU-region. Various studies have indicated that much more biomass could become available – even while serving the needs in other, non-energy markets, within the EU itself.[28]

With the change from today's feedstock base (still largely based on starch, sugar and vegetable oils) to woody and other lignocellulosic residues and waste streams, new technology needs to be developed and deployed, fit for these woody biomass streams. These types of biomass are currently used for electricity and/or hear generation, e.g. via co-firing in coal-fired power stations or in CHP-plants for district heating. It is envisaged towards 2050 that electricity generation by then will be dominated by solar, wind and geothermal sources. In that transition the biomass resources used for electricity and heat generation could well be redirected to production facilities for the production of transport fuels and/or chemical base components. These market changes, as result of the transition to a renewable energy supply system, are often overlooked when assessing biomass availability.

Other trends that may become relevant for the UPEI-members and the member's members are that:

- energy supply systems will be largely based on renewable energy, with a much higher degree of variability – requesting temporary storage of electricity, and
- the energy system at the same time is transforming from a centralised to a decentralised system, with (renewable) energy production dispersed over land

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[28] See e.g. PWC (2017), Sustainable and optimal use of biomass for energy in the EU beyond 2020. The EU project S2Biom (www.s2biom.eu) estimated in 2016 that the 2030 base potential (which includes the sustainability criteria as stated within the Renewable Energy Directive I) amounts to 1.1 billion tonnes of dry lignocellulosic biomass per year. In both projects these potentials – for which efforts are needed to achieve production level and mobilization – are well beyond the planned share of biomass use for energy in 2030.

(or produced on concentrated spots at sea) and not always well connected to where demand occurs – again this might require transforming surplus of energy in easy to handle and process forms of stored energy.

The expected growth of renewable electricity is for that reason expected to also boost innovation in the production of socalled e-fuels.

Chapter 5 highlighted that the volumes in energy (expressed in Mtoe or PJ) needed in EU transport might be at similar levels as they are today. Both electricity and biofuels will be dominant factors in the energy mix. The EU climate objectives even indicate that ambitions for these new energy carriers have to be scaled up significantly to secure sufficient decrease in CO_2-emissions in European transport. While in 2030 both electricity and biofuels (and to a lesser content e-fuels) are still not the dominant energy options, by 2050 they will probably be (and e-fuels might have taken over the role of biofuels for a large part).

UPEI members need to carefully reconsider these developments and see how to adapt to this. Liquid infrastructure will last, but segments to deliver to might change, and to secure offset in markets a need to move upstream in the supply chain might be as smart strategy. Understanding which technologies are crucial to produce low-carbon liquid and gaseous fuels is needed. Above all, different from today's mode of operation, the balance within the supply chain shifts: providing final product to the end users will only possible for those that are in control or have secured access to the feedstock upstream in the chain. Developing competencies in that upstream area, or establishing strong, full supply chain covering alliances, might be strategies to further explore. In addition to this, another potential strategy would be to strengthen the competencies in the field of energy storage. In today's business storage may be seen as a necessary element In the logistical operations, in a future setting the value of storing energy in energy dense intermediate products might increase, thus containing additional value to be captured by companies.

Annex A on Technology Readiness Levels

Within the EU Horizon 2020 Research and Development programmes the following technology status levels are used:

- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Source:
https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

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