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BioTheRoS

Collaborative actions to bring novel **BIO**fuels **THE**rmochemical **RO**utes into industrial **S**cale

MAPPING OF GLOBAL POLICY FRAMEWORK CREATING SUSTAINABLE BIOFUELS DEMAND

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Disclaimer

Executive Summary

In this report EU-level and global legislation and initiatives on sustainable biofuels in the transport sector have been mapped, and the impact on the market demand for sustainable biofuels has been assessed. This includes the EU policy framework and legislation, international efforts – specifically CORSIA (aviation) the IMO (maritime) – and USA, Canada, India and Brazil.

The EU policy framework has undergone several changes which included revisions of the Renewable energy Directive, ReFuelEU Aviation, FuelEU maritime and the EU-ETS System. From this policy framework its clear that the EU specifically targets Aviation and Maritime carbon emissions, with emphasis on advanced biofuels and RFNBOs.

International efforts, such as those of CORSIA (for aviation) and the IMO (for maritime emissions) show that there is some appetite to lower GHG related emissions, though the targets, expected efforts and enforcement mechanisms are often less well developed than those in (f.e.) EU and USA.

The USA supports biofuels via its Renewable Fuel Standard and the Inflation Reduction Act. Advanced biofuels receive additional support, and in the USA national policies are complemented by state-level initiatives, such as those in California. The Inflation Reduction Act has significant effect on the biofuels market. Canada has its own policy framework – called the Clean Fuel Standard – aimed at reducing the carbon intensity of its fuels. In general, the EU is more prescriptive than the USA or Canada in terms of what support is granted to specific biofuel types.

Brazil is a large global biofuels producer, partly through policies like Renovabio and the more Recent "Fuels of the Future" program. Despite an alignment with international standards, such as the EU RED III, Brazilian production is still dominated by first generation fuels, which is seen as a challenge. Biofuels demand is still rising, spurred by recent policies that set clear targets, though the emphasis is on land transport and less on aviation and maritime applications.

India has – like Brazil – seen remarkable growth in biofuels in recent years, especially with respect to ethanol. Production is dominated by first-generation feedstocks, and not a lot of efforts are expended on advanced biofuels. Focus is on land transport, and policies to increase biofuels in aviation and maritime transport are still evolving.

Despite the diverse international policy landscape on biofuels, there are many liquid transport biofuels initiatives. Because of that, only some of these – focussed on SAF and marine fuel production – are described in this report.

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List of abbreviations

ANN	Artificial Neural Network
ATJ	Alcohol to Jet
CCU	Carbon Capture and Utilization
CFD	Computational Fluid Dynamics
DFB	Dual Fluidized Bed
DSS	Decision support system
EU	European Union
FPBO	Fast Pyrolysis Bio Oil
FT	Fischer Tropsch
HDT	Hydrotreating
HEFA	Hydroprocessed Esters and Fatty Acids
HPO	Hydrotreated Pyrolysis Oil
HVO	Hydroprocessed Vegetable Oil
MCDA	Multi - Criteria Decision Analysis
PFD	Process flow diagram
SAF	Sustainable Aviation Fuel
SPO	Stabilized Pyrolysis Oil
RED	Renewable Energy Directive
RFNBO	Renewable fuel of non-biological origin

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1 Introduction

1.1 The BioTheRoS project

Two thermochemical biofuel production technologies form the core value chains of the BioTheRoS project: pyrolysis and gasification. Although these technologies are different, within this project synergies are foreseen by applying a multidisciplinary stepwise approach including feedstock selection, pilot experimental validation, scaleup simulation and modelling, seeking synergies in fuel blends between the fuels, value chain improvement, in particular through CCU and renewable hydrogen, a sustainable scale-up approach, social, sustainability and technoeconomic assessments, all linked to international cooperation activities to maximise the contribution to global knowledge building, and cost-effective, sustainable scale up of thermochemical advanced biofuels.

1.2 The global policy framework

The EU considers that by far the most serious challenge facing our transport sector is to significantly reduce its emissions and become more sustainable. While many sectors in the EU show decreasing GHG emissions, the transport sector is the only sector where emissions are still above their 1990 level, despite the drop caused by the COVID-19 pandemic. Currently, less than 1% of all fuels used in aviation and shipping are sustainable, i.e. non-fossil fuels. Urgent actions to substantially increase the levels of renewable energy sources in the aviation and shipping sectors are needed in order to achieve the Paris climate targets, a plethora of technologies are being considered by both the aviation and shipping sectors. However, the need for drop-in sustainable biofuels is obvious and is perceived as key decarbonization pathway by industry and representatives of these sectors. The market for sustainable biofuels is shaped by the EU and global legislative framework and its implementation in the different countries. For example, the EU's Renewable energy Directive (RED III) includes advanced biofuels targets of 2.25% instead of 1.75% in 2030, and the Fit for 55 package includes targets for renewable transport fuels for marine and air, creating opportunities for advanced biofuels. In addition, the demand for advanced biofuels in the USA and Canada is promoted via the US Renewable Fuel Standard and Canada's Clean Fuel Standard. Moreover, Brazil and India actively promote (advanced) biofuels as a way to mitigate climate change, and international mechanisms such as CORSIA are in place to support sustainable aviation fuels.

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Putting into context and as we can see in the Figure 1-1 on the left the growth demand of biofuels by countries with an advanced economy and on the right by those countries with an emerging economy is shown. We see how the difference is clear between the two, mainly due to the type of resources to obtain these fuels and the deployment of the technology to consume these biofuels. For example, the number of vehicles adapted to use a mixture of ethanol and gasoline is not the same in one country as in another. It should be added that in countries with emerging economies, the production, and the consumption of SAF is very low, due to the high cost of investment, in addition to different logistics in the sector.

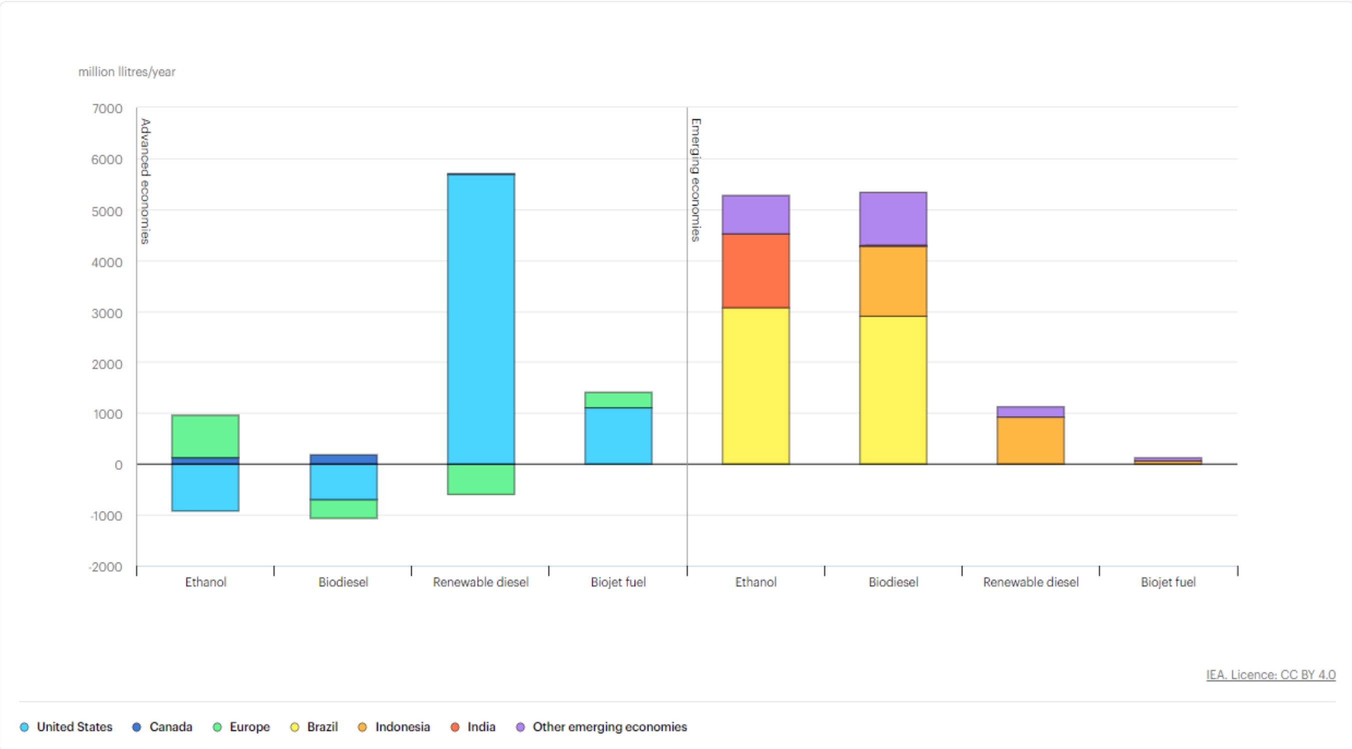

Figure 1-1 Biofuel demand growth by fuel and region, left countries with an advanced economy, on the right an emerging economy.,2022-2024.

1.3 Scope of this report

This Deliverable (D6.1) shows the results of BioTheRos Task 6.1 "Mapping of global policy framework creating sustainable biofuels demand". In this report EU-level and global legislation and initiatives on sustainable biofuels in the transport sector have been mapped, and the impact on the market demand for sustainable biofuels has been assessed. This includes the legislation under the 'Fit for 55' package currently revising the entire EU 2030 climate and energy framework (i.e. ReFuelEU Aviation, FuelEU maritime, EU-ETS phase 4 proposals) (chapter 2), the policy framework of the USA and Canada (i.e. US

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Renewable Fuels Standard (RFS), the California Low Carbon Fuel Standard (LCFS) and the Canadian Clean Fuel Standard) (chapter 4), and the policy framework of Brazil and India (Chapter 5 and 6). Furthermore, impacts of global initiatives such as The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and strategies to reduce GHG emissions by the International Maritime Organisation (IMO) on the demand for sustainable biofuels have been investigated (Chapter 3).

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2 EU Policy framework

2.1 General overview of policy drivers in EU

The EU is signatory to the Paris Agreement as well as previous Climate Agreements. For this purpose, the EU has implemented the EU Climate Law which includes the obligation to reduce net Greenhouse Gas (GHG) emissions by 55% compared to 1990 in 2030 and to achieve climate neutrality by 2050, that entails net-zero GHG emissions for the EU. To achieve such steep emission reduction and reach the EU climate neutrality goal all sectors will need to eliminate emissions or compensate for any remaining emissions. In this context transport is particularly relevant as it is a sector which has historically seen emissions rising and includes segments that by many are considered as hard to abate (e.g., road freight, aviation and maritime) (European Commission 2024) [1]. On July 14, 2021, the EC presented the "Fit for 55" policy package which introduced new or included amendments to 13 policy instruments in order to help achieve the EU Climate Law target of 55% GHG emission reduction in 2030. On occasion, policy instruments address also the trajectory after 2030 to help achieve the climate neutrality target (e.g., ReFuelEU Aviation, FuelEU Maritime). RePowerEU aims at strengthening the policies which reduce the dependence of the EU on Russian imports of gas (and oil). This has led to the suggestion to strengthen a number of policies included in the "Fit for 55" policy proposal package resulting in an upward revision of several "Fit for 55" targets.

2.2 Policy framework at EU level

In the next sections the legislation with potentially the highest impact on advanced biofuels production are investigated in more detail. These are:

- Renewable Energy Directive (section 2.2.1)
- ReFuel Aviation (section 2.2.2)
- FuelEU Maritime (section 2.2.3)
- EU-ETS (section 2.2.4).

2.2.1 Renewable energy Directive – RED III

The Renewable Energy Directive is the legal framework for the development of clean energy across all sectors of the EU economy and is an updated version and extension of the RED I, published in 2009 and RED II, published in 2018. All changes to the RED II (Directive EU 2018/2001 on the promotion of the use of energy from renewable sources) can be found in Directive 2023/2413, but for readability, it is advised to consult the consolidated text, which we will further refer to as RED III [2].

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The RED III Article 3 defines a binding overall union target of the share of energy from renewable sources in the Union's gross final consumption of energy of at least 42.5% in 2030, while efforts will be made to achieve 45%. In article 25 a complex of targets and sub-targets for renewable energy in the transport sector can be found. First of all, each Member State will take care that the amount of renewable fuels and renewable electricity supplied to the transport sector leads to a share of renewable energy within the final consumption of energy in the transport sector of at least **29% by 2030 (**Art 25.1a), which is a considerable increase compared to the **RED II that states a target of 14%.** Instead of working with this targets, Member States can also decide to work with a GHG intensity reduction of at least 14.5% by 2030. Regardless the calculation method chosen by Members States, for advanced biofuels and biogas produced from the feedstock listed in part A of Annex IX and RFNBOs, RED III Art 25.1(b) sets **a joint target of 5.5%,** of which minimally 1% from renewable fuels of non-biological origin (RFNBOs), e.g. renewable hydrogen and e-fuels, leaving a target of 4.5% or less, depending on the RFNBO share, for biogas and advanced biofuels produced from Annex IX-A feedstocks. In the RED II an advanced biofuels target of 3.5% was established.

It is important to realise that within the RED II for the **denominator**, the energy content of road- and rail- transport fuels was used (RED II Art 27.1(a)), while in the RED III for the calculation of the denominator all fuels supplied to the transport sector shall be taken into account. The "transport sector" is not further defined in the RED III. Eurostat data on transport covers five main types of transport modes: air, inland waterway, rail, road, and maritime (sea) [3]. RED III Art 27.5 states that the amount of energy supplied to the maritime transport sector shall, as a proportion of that Member State's gross final consumption of energy, be considered to be no more than **13%**. Similarly, RED III Art 7.5 states *"In calculating a Member State's gross final consumption of energy for the purposes of measuring its compliance with the targets and indicative trajectory laid down in this Directive, the amount of energy consumed in aviation shall, as a proportion of that Member State's gross final consumption of energy, be considered to be no more than **6.18%**"*. Although not explicitly mentioned, we assume that energy used for inland navigation should be fully included in the determination of the denominator.

The gross final energy consumption is defined in the RED III as *"the energy commodities delivered for energy purposes to industry, transport, households, services including public services, agriculture, forestry and fisheries, the consumption of electricity and heat by the energy branch for electricity and heat production, and losses of electricity and heat in distribution and transmission"*. Energy commodities for non-energy purposes, for example natural gas for production of chemicals, are excluded. Based on Eurostat data of 2021 [4], with the exception of the energy consumption in aviation and international

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maritime bunkers, for which 2019 (pre-corona) data was used, considering that the denominator Belgium and the Netherlands is reduced because of its large maritime bunker share, and assuming 20% reduction of consumption due to energy efficiency measures until 2030, **the gross final energy consumption of the EU in 2030 is estimated to be 274.7 Mtoe**.

For the calculation of the **numerator**, that is the amount of energy from renewable sources consumed in the transport sector, the **energy content of all types of energy from renewable sources supplied to all transport modes**, including to international marine bunkers, in the territory of each member State shall be considered. Members states may also consider recycled carbon fuels. Moreover, like in the RED II, in the RED III in various cases multi-counting is applied (Art 27.2):

- The share of biofuels and biogas from Annex IX [part A and B] and RFNBOs shall be considered twice its energy content.
- The share of renewable electricity to road vehicles shall be counted 4 times its energy content.
- The share of renewable electricity to rail transport may be counted 1.5 times its energy content.
- The share of advanced biofuels and biogas produced from Annex IX part A, supplied to the aviation and maritime transport modes shall be considered 1.2 times its energy content. This is on top of the other multiple counting.
- The share of RFNBOs supplied to the aviation and maritime transport modes shall be considered 1.5 times its energy content. This is on top op the other multiple counting.
- The share of biofuels and biogas produced from Annex IX part B in the energy content of fuels and electricity supplied shall be limited to 1.7%. However, Member States may where justified, increase this limit (Art 27.2 last part), and the EC can adopt delegated acts to increase this limit (Art 27.3).

The resulting RED III demand of advanced biofuels, Annex IX part B based biofuels and RFNBOs are presented in Table 2-1. Because of the double counting, only half of the physical quantity of biofuel or RFNBO is needed. In case of UCO the energy content is limited to 1.7%, so after double counting it can contribute 2 x 1.7% = 3.4% to the RED III target. Please note that the RED III has to be implemented at Member State level, meaning that this calculation is just indicative.

Table 2-1: Quantification of the RED III targets into total energy demand within the EU-27

RED III targets	Contribution to target	Double counting	Physical quantity (ktoe)
Advanced biofuels	4.5%	2 x	6,180
RFNBOs	1.0%	2 x	1,373
Annex IX B based biofuels (UCO)	3.4%	2 x	4,669

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Please note that the biofuels and RFNBOs used in aviation following ReFuelAviation (see next section) also contribute to the RED III targets and receive an additional multiple counting of a factor 1.2. Therefore, it can be anticipated that 2,160 ktoe of aviation biofuels (and recycled carbon fuels) in 2030 as presented in **Table 2-2** will be produced, which receives an additional multiple counting of a factor 1.2, covering 1.2 x 2160 = 2,592 ktoe of the physical quantity as presented in **Table 2-1**. Depending on the feedstock used, part of this volume will count to the advanced biofuels target if Annex IX-A feedstock is used, or contribute to the overall biofuels target, if Annex I-B feedstocks are used and the limit of 1.7% is not yet reached.

2.2.2 ReFuelEU Aviation

Overview

ReFuelEU Aviation is an EU regulation, directly applicable to all Member States, setting targets to the supply of sustainable aviation fuel (SAF) in EU airports. It is regarded as the world's most comprehensive framework stimulating SAF. ReFuelEU Aviation has the following main provisions [5]:

- The obligation for aviation fuel suppliers to ensure that all fuel made available to aircraft operators at EU airports contains a minimum share of SAF from 2025 and, from 2030, a minimum share of synthetic fuels, with both shares increasing progressively until 2050. Fuel suppliers will have to incorporate 2% SAF in 2025, 6% in 2030 and 70% in 2050. From 2030, 1,2% of fuels must also be synthetic fuels, rising to 35% in 2050.
- The obligation for aircraft operators to ensure that the yearly quantity of aviation fuel uplifted at a given EU airport is at least 90% of the yearly aviation fuel required, to avoid tankering practices which would bring additional emissions from extra weight.
- The scope of eligible sustainable aviation fuels and synthetic aviation fuels includes certified biofuels, renewable fuels of non-biological origin (including renewable hydrogen) and recycled carbon aviation fuels complying with the Renewable Energy Directive (RED) sustainability and emissions saving criteria, up to a maximum of 70% with the exception of biofuels from food and feed crops, as well as low-carbon aviation fuels (including low-carbon hydrogen), which can be used to reach the minimum shares in the respective part of the regulation.
- Rules on the competent authorities, to be designated by the member states to enforce this regulation, and rules on fines.
- The creation of a Union labelling scheme about environmental performance for aircraft operators using SAF, which will help consumers make informed choices and will promote greener flights.
- Data collection and reporting obligations for fuel suppliers and aircraft operators enabling to monitor the effects of this regulation on the competitiveness of EU operators and platforms.

The targets and implications for the demand for biofuels derived SAF, assuming a flat demand of 45 Mtoe for the EU27 are presented in **Table 2-2**.

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Table 2-2: SAF targets of ReFuelEU Aviation, and estimation of derived SAF demand in the EU27

Year	SAF[a]	Synthetic sub-target	Biofuels & recycled carbon fuels	Total kerosene demand (Mtoe)	Total SAF demand (Mtoe)	Synthetic sub-target (Mtoe)	Biofuels & recycled carbon fuels (Mtoe)
2025 - 2029	2%	0%	2%	45	0.9	0.0	0.9
2030 - 2031	6%	1.2%[b]	4.8%	45	2.7	0.5	2.2
2031 - 2034	6%	2.0%[c]	4.0%	45	2.7	0.9	1.8
2035 - 2039	20%	5%	15%	45	9.0	2.3	6.8
2040 - 2044	34%	10%	24%	45	15.3	4.5	10.8
2045 - 2049	42%	15%	27%	45	18.9	6.8	12.2
2050 and further	70%	35%	35%	45	31.5	15.8	15.8

[a] Please note that renewable hydrogen for aviation and low-carbon aviation fuels (e-kerosene made from nuclear power also contribute to this target (See ReFuelEU Aviation Article 4.1). [b] minimal 0.7% per year, average minimal 1.2% over the period [b] min 1.2%/year, average 2.0% over the period

As shown in the table aviation biofuels are together with synthetic aviation biofuels and recycle carbon aviation fuels in one SAF target. Therefore, it is relevant to assess how these fuels are exactly defined.

Sustainable aviation fuels (SAF) are defined as a) synthetic aviation fuels, b) aviation biofuels and c) recycled carbon fuels.

Synthetic aviation fuels means aviation fuels that are of non-biological origin, the energy content of which is derived from non-fossil low-carbon hydrogen, which meet lifecycle emissions savings threshold of 70% and the methodologies for assessing such lifecycle emissions savings pursuant to relevant Union law [i.e. Commission Delegated Regulations 2023/1185 on GHG emissions savings of recycled carbon fuels and RFNBOs]. In short this fuel is called e-kerosene.

Aviation biofuels means i) advanced biofuels as defined in the RED II, i.e. produced from feedstock listed in Part A of Annex IX, ii) biofuels produced from feedstock listed in Part B of Annex IX, or iii) biofuels, i.e. liquid fuel transported from biomass, with the exception of biofuels produced from food and feed crops, and which comply with the sustainable and lifecycle emissions savings criteria laid down in RED II Article 29, and certified in compliance with RED Article 30. Moreover, ReFuelEU Aviation Article 5 excludes SAF produced from intermediate crops, palm fatty acid distillate and palm and soy-derived materials, and soap stock and its derivatives, except if they would be listed in RED III Annex IX. In short, aviation biofuels consist of non-food and feed biofuels.

Recycled carbon aviation fuels (RCF) means aviation fuels that are recycled carbon fuels, as defined in the RED II, i.e., liquid and gaseous fuels that are produced from liquid or solid waste streams of non-

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renewable origin which are not suitable for material recovery with accordance with Article 4 or the Directive 2008/98/ EC, or from waste processing gas and exhaust gas of non-renewable origin which are produces and an unavoidable and unintentional consequence of the production process in industrial installations, which comply with the sustainability and lifecycle emission savings criteria laid down in RED II Article 29 and are certified in compliance with RED II Article 30. These are aviation fuels which energy content is derived from waste fossil energy, i.e. waste steel mill or refinery waste gases.

Two non-SAF fuels, i.e. ***renewable hydrogen for aviation***[1] and ***low-carbon aviation fuel***, i.e. hydrogen and aviation fuels produced with hydrogen from nuclear power, can also be used for meeting the "SAF"-target.

Analysis

Given that synthetic aviation fuels are expected to be very costly to produce, it can be assumed that the volumes of synthetic aviation fuels will just meet the sub-target. However, 20 Million EU allowances (EUA) are available for aircraft operators covering a large part of the price difference between kerosene and SAF, giving synthetic aviation fuels the highest stimulation. See section 2.2.4.

The options for RCF need to be further investigated, but the first impression is that the total production capacity will be limited.

Within aviation biofuels, a strong demand for Annex IX part B-aviation fuels can be expected for the production of HEFA, which is currently already possible at commercial scale. ReFuelEU Aviation does not put a cap on Annex IX part B biofuels. However, at a certain production level point Annex IX part B aviation fuels count towards ReFuelEU Aviation but not anymore to RED III, which has a cap on Annex IX part B biofuels.

Moreover, it has to be investigated which "non-food/feed/Annex IX part A&B fuels" could appear on the market. One example would be category 3 animal fats. Please note this group of biofuels is limited of 3% of the aviation fuels supplied for meeting the SAF target (Art. 4.4).

Intermediate crops are excluded from ReFuelEU Aviation, but could become part of the revised RED III Annex IX, which would make them eligible. If this group of fuels contains easy to convert sugar, starch or oil feedstocks – intermediate crops may qualify - they could be produced cheaper than the pyrolysis

[1] Aviation fuel is defined as drop-in fuel manufactured for direct use by aircraft (See ReFuelEU Aviation Art. 3(6). As renewable hydrogen is not a drop in fuel, which may be the reason that it is mentioned separately, and not part of synthetic aviation fuels.

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and gasification based advanced biofuels that are the topic of BioTheRos. This all will be subject to further assessment of market dynamics, as foreseen in Task 6.2.

Flexibility period

From 1 January 2025 until 31 December 2034, aviation fuel suppliers have the flexibility to average supplies of SAF to Union airports for compliance with the minimum shares. This means that fuel suppliers can choose to supply all their SAF at one or more of the airports they supply, if that is logistically more attractive [6].

Certainty of the SAF target

If an aviation fuel supplier fails to supply the minimum shares of SAF and synthetic aviation fuels, it shall at least complement that shortfall in the subsequent reporting period. Failing to comply with the minimum shares of SAF means fuel suppliers are liable to pay a fine of at least twice the difference between the price of conventional aviation fuel and SAF in that year (Art. 12.4). If aircraft operators fail to uplift less than 90% of the yearly aviation fuel required, they have to pay a fine, to be further defined by the Member States (Art. 12.2). The European Aviation Safety Agency (EASA) is tasked with collecting market intelligence on SAF pricing every year. EU airports managing bodies are subject to a fine if they fail to take the necessary measures to provide adequate access by aircraft operators to aviation fuels. Overall, the certainty that the SAF targets have to be met is high.

One comment to be made here is that by 1 January 2027 and every four years thereafter, a report will be established evaluating the possible need to revise the scope of ReFuelEU Aviation regulation, it definitions, targets and level of fines. Competitiveness of Union air carriers and airport hubs have to be assessed, as well as carbon leakage – e.g. other international hubs taking over international flights – especially in absence of a mandatory scheme at international level. The report shall consider whether ReFuelEU Aviation regulation should be amended.

2.2.3 FuelEU Maritime

The FuelEU Maritime [7] regulation does not specify which fuels must be used in shipping but rather demands that the greenhouse gas intensity of fuels is lowered over time. The level of greenhouse gas savings that must be achieved increases every five years: 2% as of 2025, 6% as of 2030, 14.5% as of 2035, 31% as of 2040, 62% as of 2045 and 80% as of 2050, applicable to ships above 5000 tonnes.

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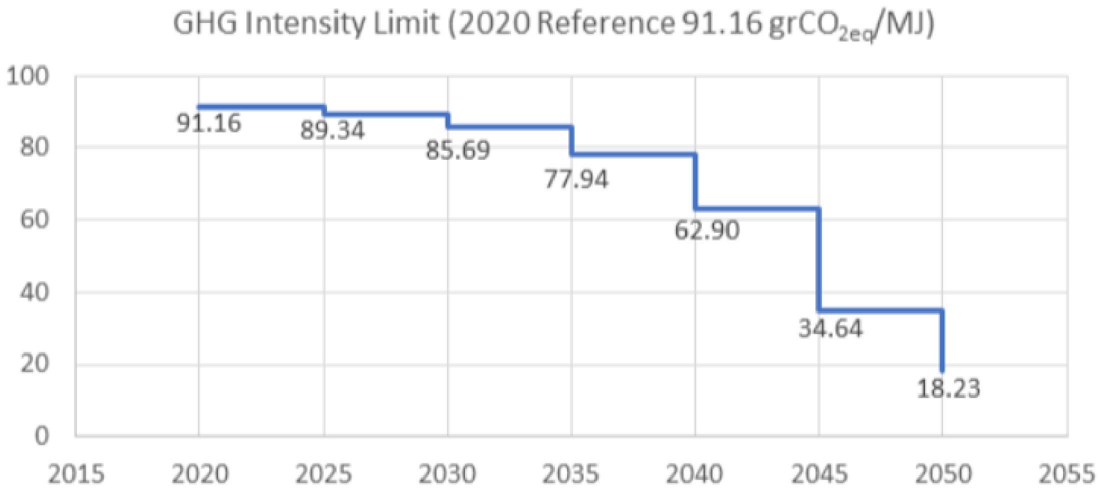

Figure 2-1: GHG intensity limit under FuelEU Maritime.

From 2030, container ships and passenger ships are required to connect to shore power when at berth for more than two hours in a Trans-European Transport Network (TEN-T) port. From 2035, the requirement applies to all ports where shore power is available [8].

Ship owners can take various measures to reduce their GHG intensity, like using fossil low carbon fuels (like natural gas), biofuels, RFNBOs, and/or measures like wind-assisted propulsion. Biofuels and biogas that do not comply with the sustainability and GHG emissions saving criteria set out in Article 29 of the RED III, or that are produced from food and feed crops shall be considered to have the same emission factors as the least favourable fossil fuel pathway for that type of fuel. This means that it makes no sense to use first generation ethanol and biodiesel.

Compliance

Ships with a higher GHG intensity than the threshold must pay a remedial penalty proportional to their compliance deficit. The compliance deficit is the difference between the reference GHG intensity and the actual one, multiplied with the energy consumption, which is calculated by multiplying the mass of the fuel along with the lower calorific value (LCV) and the electricity delivered at ship. Subsequently, the compliance balance deficit is converted to energy, being divided with the actual GHG intensity of the vessel. The non-compliant energy as calculated, is finally multiplied with a penalty of EUR 2,400 per tonne very low sulphur fuel oil (VLSFO) equivalent energy which is equal to around EUR 0.058 per MJ of non-compliant energy (ABS 2024) [9].

2.2.4 EU-ETS

From 1 January 2024 until 31 December 2030, 20 million carbon allowances from the Aviation ETS [10] will be reserved to finance SAF use by ETS-eligible aircraft operators. This means that SAF allowances

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can only be used on intra-EU flights, representing about 40% of total aviation fuel use in the EU [11]. Carbon allowances are taken out of the pool of total allowances that are available for aviation and are allocated to airlines using SAF. The difference in costs between the kerosene and SAF, taking into account the advantage of avoided carbon costs for not using kerosene, is compensated for:

- 100% in case of SAF used at small airports that are not classified as Union airports in the context of ReFuelEU or airports on remote islands
- 95% in case of RFNBOs (synthetic biofuels)
- 70% in case of advanced biofuels and renewable hydrogen
- 50% in case of other eligible SAF (for example from UCO or animal fats)

As shown in the example in **Table 2-3** below, the high compensation in EUAs makes synthetic biofuels for airlines probably cheaper to use than UCO or advanced biofuels, as long as the budget of 20 Million EUAs is not exhausted. In the example, assuming an advanced biofuels price of 7000 €/tonne and a UCO SAF price of 3500 €/tonne, for airlines UCO SAF is cheaper than the use of advanced biofuels. The price of advanced biofuels should drop to 5256 €/tonne to become competitive with UCO SAF, i.e. be roughly maximally 50% more expensive compared to UCO SAF.

Table 2-3: example calculation of the compensation of the use of SAF by airline operators via EU-ETS

Type of SAF	**UCO SAF**	**Advanced biofuels and renewable H_2**	**Synthetic fuels**	**Unit**
SAF price	3500	7000	14000	€/tonne
Kerosene price	600	600	600	€/tonne
Price difference jet fuel and SAF[a)]	2900	6400	13400	€/tonne
Avoided ETS carbon costs using SAF[b)]	252	252	252	€/tonne
Net price difference kerosene and SAF before compensation	2648	6148	13148	€/tonne
Applied percentage compensation	50%	70%	95%	
Compensation via carbon allowances	1324	4304	12491	€/tonne
# of carbon allowances supplied to airline	17	54	156	EUAs/tonne
Impact on costs for airlines using SAF				
Total costs of using SAF without compensation	3248	6748	13748	€/tonne
Total costs of using SAF with compensation	1924	2444	1257	€/tonne

[a)] We assumed the same energy content per tonne fuel [b)] Assuming avoiding the emission of 3.15 tCO2/MT kerosene at an EU-ETS price of 80 €/tonne.

As shown in **Table 2-2** the total demand for SAF in the period 2025-2029 is estimated at 0.9 Mtoe per year, which is about 900,000 tonnes of SAF. Assuming that the 20 million allowances are supplied equally between 2024 – 2030, in this period of seven years 2.86 million EUAs are available to compensate airlines for the use of SAF. In the most likely scenario, these EUA can be used to support airlines for the use of 2.86 million EUAs divided 17 EUAs/tonne SAF [12] which equals 173 ktonnes of

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UCO SAF per year, which is about 19% of the 900 ktonnes SAF required per year. In the less likely case of 100% advanced biofuels, about 74 ktonnes SAF based on advanced biofuels could be supported (8% of the SAF target). In the unlikely case of 100% RFNBOs, only 18 ktonnes/year of synthetic biofuels could be supported (2% of the SAF target). This illustrated the extremely high level of support of synthetic biofuels (95% of the difference with kerosene) as well as the low impact on greening aviation. More likely, mainly, or only UCO SAF will benefit from the offered support. The relatively short time span of the support via EU-ETS offered until 2030, will make it difficult for non-commercial technologies like synthetic biofuels to benefit from the EU-ETS support. Moreover, even if in place, it is uncertain which airlines will be compensated in this first-come-first-serve arrangement. Please note, the calculation is based on several assumptions. The Commission will publish the cost differences on a yearly basis for the previous year. Moreover, the Commission is empowered to adopt delegated acts with further detailed rules for the yearly calculation of the cost difference.

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[3] https://ec.europa.eu/eurostat/web/transport

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[5] https://www.consilium.europa.eu/en/press/press-releases/2023/10/09/refueleu-aviation-initiative-council-adopts-new-law-to-decarbonise-the-aviation-sector/

[6] See https://skynrg.com/refueleu-how-it-will-shape-the-saf-market/

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[10] Directive 2003/87/EC of the European Parliament and of the Council of of 13 October 2003 establishing a system for greenhouse gas emission allowance trading within the Union and amending Council Directive 96/61/EC. Usually referred to as EU-ETS.

[11] This text is based on the clear description as found here: https://skynrg.com/refueleu-how-it-will-shape-the-saf-market/

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3 International policy framework

3.1 Aviation global policy initiatives

Aviation only accounted for 2% of global energy related CO_2-emissions in 2022, but growth of the aviation GHG emissions has in recent decades outstripped growth in others transport sectors. It is generally recognised that aviation is one of the challenging sectors to decarbonise [1].

Besides policy initiatives to decarbonise aviation in countries and regions such as the US and EU, global aviation decarbonisation policy is evolving through the ICAO. The ICAO (International Civil Aviation Organization) is a United Nations agency, with 193 countries as members, covering together nearly all global civil aviation. Whereas many other carbon emissions are dealt with through the UNFCCC agency, the ICAO has aviation emission reduction in its scope. The ICAO is different from other international aviation organisations such as IATA, who has airlines as members.

A key development in global aviation decarbonisation was the adoption of the Long-Term Aspirational Goal (LTAG) of net zero carbon emissions from international aviation by 2050, during the 41rst meeting of the ICAO in 2020 [2].

More recently, the ICAO has adopted a "Global framework for aviation's decarbonization efforts" [3], during its November 2023 meeting. According to ICAO, such a framework is necessary to scale-up development and deployment of SAF (Sustainable Aviation Fuel), LCAF (Low-Carbon Aviation Fuels), and other aviation cleaner energies. It is the intention that this framework provides greater clarity, consistency, and predictability for stakeholders. The framework consists of four building blocks: Policy and planning, Regulatory frameworks, Implementation support, and Financing. These building blocks still need to be developed further, but one concrete change already agreed is the aim for 5% less carbon intensive aviation fuels in 2030 compared to fossil fuels used today.

Besides these recent policy developments, one of the existing measures of ICAO to reduce carbon emissions in aviation is the CORSIA agreement. This measure is discussed in more detail in the following paragraphs.

3.1.1 CORSIA overview

CORSIA stands for Carbon Offsetting and Reduction Scheme for International Aviation. It is a global offsetting mechanism, which aims to limit aviation emissions to a fixed emissions 'ceiling', through

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compensation of emissions above a certain level. As such, it is a global market-based measure; the first of its kind for achieving decarbonisation.

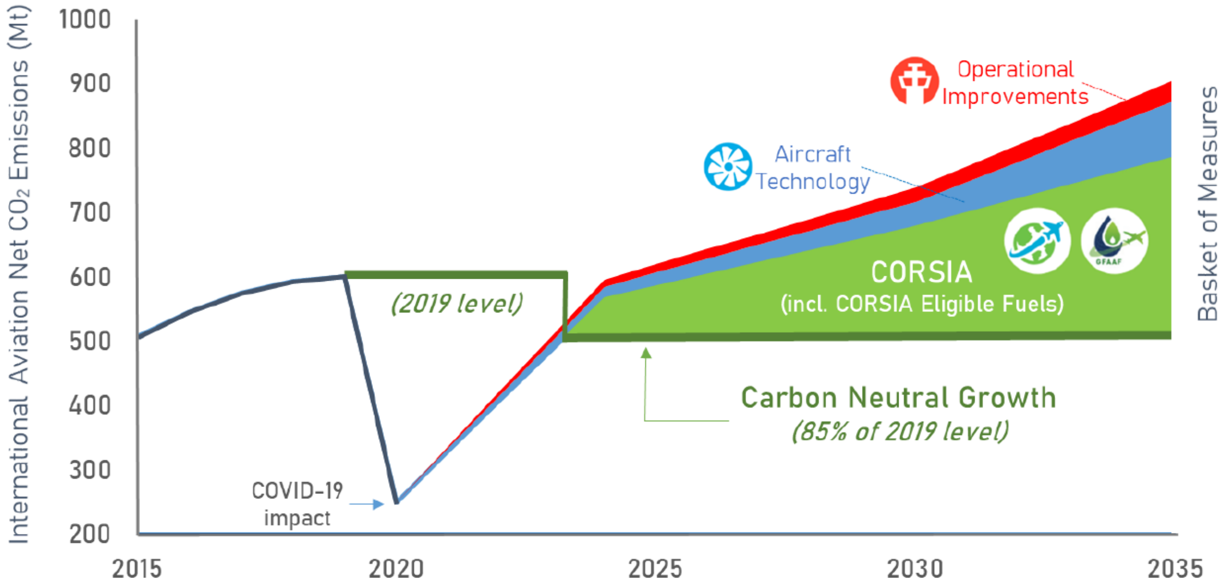

Figure 3-1: Envisaged contribution of CORSIA to reduction of aviation CO2 emissions

The logic behind CORSIA is shown in Figure 3-1 [4]. The ICAO expects that the growth in aviation emissions can be reduced by operational improvement and better aircraft technology. Any further emission reductions needed to stay on the baseline requires carbon-offsetting measures. As shown in the graph, the baseline has been determined to be 85% of 2019 level emissions.

CORSIA is implemented in three phases: a pilot phase (2021-2023), a first phase (2024-2026), and a second phase (2027-2035). For the first two phases (2021-2026), participation is voluntary. As of January 2024, 126 states participate in CORSIA (see map).

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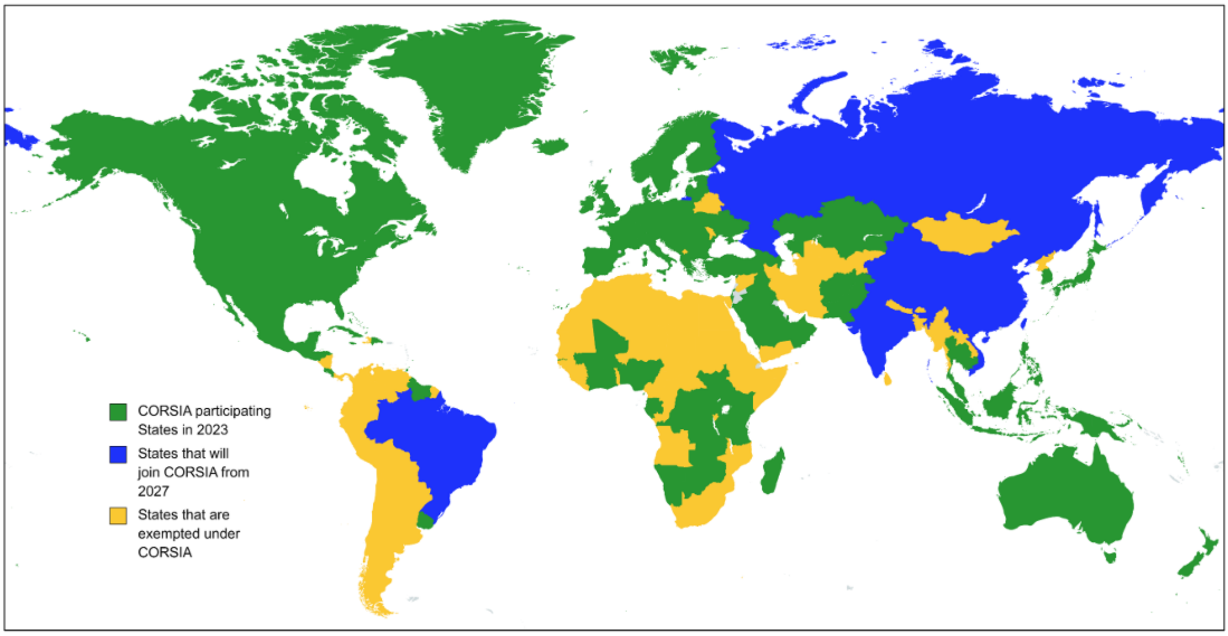

Figure 3-2: States participating in CORSIA (2023) [5]

From the map it's clear that many large countries such as US, EU, Australia, and Japan participate. India and Brazil will participate in 2027. Not all states will have to participate in the non-voluntary phase (from 2027 onwards). There are two types of exemptions:

- Small states, whose part in international aviation is less than 0.5% of the total
- Least Developed Countries (LDCs), Small Island Developing states (SIDS), and Landlocked Developing Countries (LLDCs).

These states can however participate voluntarily in CORSIA.

3.1.2 CORSIA mechanism

CORSIA covers international flights (so not domestic flights) between CORSIA member states. So flights between a CORSIA member state and a non-CORSIA member state are excluded. CO_2 emissions from domestic flights (about 50% of total aviation emissions [6]) are not covered by CORSIA. Currently, the countries that participate in the voluntary phases represent over 80% of global international aviation traffic [2].

The overall mechanism by which CORSIA operates is as follows [4]:

- All airline operators with annual emissions greater than 10,000 tonnes of CO_2 are required to report their emissions from international flights on an annual basis. Based on fuel use, CO_2 emissions shall be calculated using one (out of five available) approved method. These emission reports must be independently verified, and are then aggregated at member state level, after which they are reported to ICAO.

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- ICAO then compiles the member state reports and publishes the data, calculating the carbon offsets which each member state must acquire to maintain net carbon emissions compared to the baseline. This is thus one figure for the entire sector.
- The individual airlines are subsequently given an off-setting requirement. This off-setting requirement will be entirely sector-based until 2032. After 2032, the off-setting requirement will be for 15% based on the individual airline performance, and for 85% on the sector performance.
- During a 3-year compliance period, an airline has to fulfil its off-setting requirement, though CO_2 compensation via CORSIA-eligible SAFs, or other CO_2 emission reduction. This off-setting is subsequently reported.

Notable issues with respect to this mechanism are:

- Compliance and enforcement is entirely the responsibility of participating member states. ICAO has issued no guidance on this.
- The 3-year compliance periods of CORSIA are fixed. The first compliance period is from 2021 to 2023, and the last (the 5th) is from 2033 to 2035. Currently, CORSIA is set to end in 2035.
- Off-setting can thus be achieved via CORSIA eligible SAFs, but also via other CO_2 emission reduction units that were generated via approved CO_2 emission reduction schemes. The full list of approved schemes is available on the ICAO website and includes schemes such as VCS (Verified Carbon Standard), CDM (Clean Development Mechanism) and ACR (American Carbon Registry).

3.1.3 CORSIA and EU ETS

The EU Emission Trading System (EU ETS) is a system where the EU limits carbon emissions to a certain cap. Large emitters in the EU need to stay below their CO_2 emission cap. Trading of emission credits is allowed, which means – in theory - that emission reductions are achieved where the costs are lowest. EU Industrial and energy sectors, and aviation fall under the EU ETS. During the whole of 2023, the typical price of one EU ETS unit (one tonne of CO_2) hovered between 68.5 and 105.5 Euro [7].

EU ETS already applies to EU aviation since 2012, but until 2016 it was limited to flights within the EEA (EEA = EU plus Iceland, Liechtenstein, and Norway). This was done to facilitate the setting-up of CORSIA [8].

A large part of the EU aviation emissions allowances was freely allocated. In 2021, 15% of the EU ETS emissions from aviation were auctioned. It is the intention to limit these free allocations further to between zero and 30% in 2030 [9].

EU ETS and CORSIA are now set to co-exist, which means that – broadly speaking – CORSIA is limited to flights to and from third countries from the EEA, and ETS to flights within the EEA.

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Both the EU ETS and CORSIA are market-based measures, which means that they both rely on a market, were carbon emissions are being traded freely. There are also quite some differences, however: EU ETS is a cap-and-trade system. This means that an overall cap on the amount of carbon emissions is placed, and that these emissions can then be traded. CORSIA is an off-setting scheme, in which 'externally generated' carbon credits can be used for off-setting. This means that CORSIA by itself does not lower aviation emissions. The carbon prices in the EU ETS are roughly 20 times higher than a CORSIA offset [10].

The EU is currently implementing CORSIA and hopes that it can be strengthened. This means that participation should increase, and that it can contribute to the Long-Term Aspirational Goal (LTAG) of the ICAO to reach net zero from aviation emissions in 2050. To verify this, the EU has planned a review of CORSIA in 2026. If CORSIA is not sufficiently strengthened, the EU will also bring departing flights from EEA countries to other 3rd countries under EU ETS. In the meantime, The EU has already stipulated that flights to 3rd countries that do not participate in CORSIA – and are not exempt - will fall under EU ETS from 2027 onwards. This could help to boost the CORSIA participation rate [11].

3.1.4 CORSIA criticism

As is clear from the previous paragraphs, CORSIA has received criticism. This criticism can be summarised as follows [12]:

- CORSIA only deals with fuel-related CO_2 emissions. However, aviation causes also non-CO_2 emissions, such as via NO_x emissions, and contrails and cirrus clouds. It is estimated that these emissions cause 2/3rds of the total GHG-related aviation emissions[Error! Bookmark not defined.]. The EU C ommission estimates these non-CO_2 emissions to be a factor 2 to 4 higher than the fuel-related CO_2 emissions of aviation[Error! Bookmark not defined.], which is in the same order of magnitude.
- CORSIA is not enough for the LTAG (Long Term Aspirational Goal) of the ICAO of net-zero emissions from aviation in 2050. This is because:
  - CORSIA is scheduled to end in 2035, while the LTAG is set for 2050
  - CORSIA aims to limit emissions to 85% of the 2019 values, so it does not reduce emissions below that on its own.
- The inclusion of LCAF (Low Carbon Aviation Fuel) in CORSIA is problematic for two reasons:
  - The potential for carbon emission reduction is limited with LCAF, as most emissions occur during the combustion phase.
  - There is a risk of double counting, since there are other measures (like the EU Fuel Quality Directive) that also stimulate the use of LCAFs
- Regarding the use of off-setting carbon credits, there are questions regarding additionality and the use of vintage (older) carbon credits.
- Compliance and enforceability are left to the ICAO member states, and there is no ICAO policy on this.

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- CORSIA does not stimulate the use of SAF, since it allows off-setting with various types of carbon credit schemes. Prices for carbon credits in these schemes are low. As long as these prices for carbon credits remain low, the incentive to reduce offset obligations under CORSIA by using SAF remains very limited. SAFs are essential, however, to decarbonising the aviation sector.

From this list, it is clear that CORSIA has less relevance with respect to the actual reduction of carbon related emissions from aviation. Also, it is not expected that CORSIA in its current form will be an actual stimulus to use more SAF. What the practical consequences of CORSIA are for biofuel producers is further detailed in paragraph 3.3.

3.2 Maritime

The environmental impact of shipping is significant, contributing to global emissions of CO_2, nitrogen oxides (NO_x) and sulfur oxides (SO_x). Specifically, in 2022, international shipping accounted for about 2% of global energy-related CO_2 emissions [13]. Moreover, the sector is responsible for approximately 13% and 12% of annual global NO_x and SO_x emissions, respectively, from anthropogenic sources [14].

These figures illustrate the critical need for the shipping industry to transition towards more sustainable practices, including the adoption of biofuels. Biofuels are considered a promising solution for reducing the maritime sector's carbon footprint and meeting stringent sulphur regulations. Their compatibility with existing fleets and closer proximity to commercialization than other alternative fuels or technologies, such as ammonia or hydrogen, make them an attractive option [15]. Furthermore, the use of biofuels in shipping offers benefits in the event of spills due to their biodegradable nature. Compared to conventional marine fossil fuels, biofuels react differently in the marine environment, potentially offering a lesser environmental impact in case of accidental releases [16].

As of 2022, the utilization of biofuels in shipping has been quite low, limited mainly to demonstrations, pilots, and trials. However, there was a noticeable increase in biofuel usage with reports indicating around 930,000 tonnes of blended biofuel being bunkered in key ports like Singapore and Rotterdam, translating to about 280,000 tonnes of pure biofuels. This amount still represents a tiny fraction, roughly 0.1%, of the total maritime fuel consumption. [17]

Biofuels relevant for maritime shipping primarily include Fatty Acid Methyl Ester (FAME), Biomass to Liquid (BTL) fuels, and Hydrogenated Vegetable Oil/Hydrogenation-Derived Renewable Diesel

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(HVO/HDRD). FAME, being one of the first-generation biofuels is derived from vegetable oils, animal fats, or waste cooking oils and has been in widespread use since the 1990s [18]. Currently, it is the most commonly used biofuel in marine applications, either blended with traditional petroleum fuels or used as 100% biofuel [19]. On the other hand, potential application of BTL fuels in shipping could be significant due to their cleaner burning properties and the possibility of using a wide range of biomass feedstocks. Finally, HVO/HDRD is favoured for its improved oxidation stability and ability to blend in any proportion with conventional diesel. By 2030, its worldwide capacity is projected to reach 26 million metric tons [18].

For the global shipping sector to significantly contribute to decarbonization efforts by 2050, an estimated 250 million tonnes of oil equivalent (Mtoe) per annum of biofuels would be required. However, the global supply of biofuels is projected to reach between 500 to 1,300 Mtoe per year by 2050. This indicates that shipping could potentially need between 20% and 50% of this supply to decarbonize primarily using biofuels. [17]

The International Maritime Organization (IMO) has been at the forefront of promoting the use of biofuels aligning with its commitment to achieve a reduction in the carbon intensity of international shipping by at least 40% by 2030, and working towards net-zero GHG emissions by around 2050 [19]. IMO's recent regulations are also focusing on reducing sulphur levels in fuels. These regulations create a need for the sector to adapt, potentially through the use of more refined fuels, scrubbers, or alternative fuels like biofuels and LNG [20].

The IMO's regulatory framework, particularly under MARPOL Annex VI [21], guides the adoption and use of biofuels in shipping. A significant development came in June 2022 when the IMO approved a new "Unified Interpretation (UI)" of Regulation 18.3 MARPOL Annex VI, which clarified the use of biofuel blends. According to this UI, biofuel blends up to 30% (B30) are treated the same as conventional oil-based fuels. This provision facilitates the use of higher biofuel blends in engines certified under MARPOL Annex VI, provided these fuels do not necessitate modifications to the engine's NO_x critical components or operating values beyond those approved in the engine's Technical File [22].

In parallel, MARPOL Annex VI imposes strict regulations on bunker emissions, including limits on sulphur content and NO_x emissions, which apply to biofuels and biofuel blends. For sulphur content, the global limit is 0.50% m/m (mass by mass) outside designated Emission Control Areas (ECAs), where the limit is even lower at 0.10% m/m [21]. NO_x emission limits are tiered based on the ship's

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construction date and operating area, with more stringent requirements for newer ships and certain areas to significantly lower NO_x emissions compared to older standards.

While biofuels typically meet sulphur limits without issue, demonstrating compliance with NO_x emission limits has been more challenging. The recent regulatory updates aim to facilitate broader biofuel adoption by providing clearer guidelines and more flexible options for ships using biofuels, in order to ease compliance with NO_x limits. These revisions include the recognition of biofuel blends within existing frameworks and potentially adjusting NO_x testing protocols to account for the unique properties of biofuels. By addressing specific challenges and offering practical pathways to compliance, these updates support the maritime industry's shift towards more sustainable fuel options. [22]

The development of an internationally recognized standard defining the sustainability criteria of biofuels would support the further advancement of biofuel technologies, along with policies aimed at creating a predictable framework to reduce investment risks [15]. In terms of regulatory compliance and sustainability, the IMO emphasizes the importance of sourcing biofuels from sustainable feedstocks and using sustainable energy sources in their production. Certification schemes like the International Sustainability and Carbon Certification (ISCC) are highlighted as ways to verify the carbon neutrality of biofuels [16].

3.3 Practical consequences for market actors

3.3.1 CORSIA

The last point – the expectation that CORSIA does not stimulate the use of SAF is illustrated in Table 3-1. In this table we calculate for a typical flight with a Boeing 747- 400[2] the costs of off-setting part of the fuel-related carbon emissions. Off-setting via VCS – eligible under CORSIA – is compared to replacing the fossil kerosine with SAF. For this, two types of SAF are selected: SAF made from Used Cooking Oil (UCO), and SAF made from biomass residues (advanced biofuels). For simplicity it is assumed that in all cases 70% of the fuel-related CO2 emissions need to be compensated for. In the case of SAF this means replacing all kerosine with SAF, since the fuel-specific emission reduction of these SAF types is always less than 100% and 70% is a typical value.

[2] https://www.carbonindependent.org/22.html#:~:text=At%20a%20cruising%20speed%20of,CO2%20per%20passenger%20per%20hour.

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Table 3-1: Comparison of carbon-offsetting costs for a typical Boeing 747-400 flight with various options

Parameter	VCS off-setting	Off-setting with SAF from UCO	Off-setting with advanced biofuels	Unit
Flight distance	5,556	5,556	5,556	km
Kerosine used	59.6	59.6	59.6	tonne
Fuel-based CO_2 emissions	3.15	3.15	3.15	kg CO2/kg fuel
CO_2 reduction aimed for	70%	70%	70%	
CO_2 to be compensated	131	131	131	tonne
Costs per tonne CO_2[a]	8.34			Euro/tonne
Costs per tonne of SAF		3500	7000	Euro/tonne
Costs fossil kerosine		600	600	
Costs off-setting	**1095**	**172,840**	**381,440**	**Euro/flight**
Cost increase factor	1	158	348	-

For the costs per tonne of avoided CO_2 for the VCS system, average data from the 2023 carbon market is used[3].

What is clear from the table is that costs of replacing kerosine with SAF are far higher than compensation with voluntary carbon schemes like VCS. The last line of Table 3-1 shows that the costs of off-setting with SAF are two orders of magnitude higher than the costs of off-setting with voluntary carbon credits (or similar). This means that CORSIA provides little or no incentive to use SAF.

3.3.2 Maritime

Given the global initiatives to increase the use of biofuels in maritime applications, biofuel developers and producers are poised to play a crucial role in this transformative phase. To align with and benefit from these initiatives, there are several practical implications and steps that biofuel developers and producers can undertake to ramp up production effectively.

Biofuel developers should familiarize themselves with the international standards and regulatory frameworks guiding the use of biofuels in maritime applications, such as those set by the International Maritime Organization (IMO) [22] and regional policies like the European Union's FuelEU Maritime

[3] https://www.ecosystemmarketplace.com/articles/new-state-of-the-voluntary-carbon-markets-2023-finds-vcm-demand-concentrating-around-pricier-high-integrity-credits/#:~:text=While%20the%20volume%20of%20VCM,slightly%20to%20%246.97%20per%20ton.

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initiative [23]. Biofuels production should be tailored to meet specific requirements, such as sulphur content limits and carbon intensity rating to align with these regulations.

Sustainability criteria play also a critical role in the scalability of biofuels. Developers should invest in feedstock that is both sustainable and scalable, avoiding negative impacts on the environment or social structures. Embracing sustainability frameworks, like those proposed by the Roundtable for Sustainable Biomaterials (RSB), can guide the development of biofuels that meet these criteria. [26]

Technologies that improve the yield and reduce the energy consumption of biofuel production processes can significantly impact the market readiness and competitiveness of biofuels. Innovation in production processes is essential for increasing the efficiency and lowering the cost of biofuel production. Developers should focus on advanced technologies that convert a wide range of feedstocks into high-quality biofuels. Partnerships with maritime stakeholders, research institutions, and technology providers is essential to achieve a better understanding of market needs. Engaging with the shipping industry can also help in tailoring biofuel products to meet the specific requirements of marine engines and fuel systems. [15], [26]

Understanding and leveraging financial incentives, such as subsidies, tax credits, and carbon pricing mechanisms, can be crucial for biofuel developers. For example, incentives like the Renewable Fuel Standard’s Renewable Identification Numbers (RINs) and Low Carbon Fuel Standard (LCFS) credits in the United States can narrow the price gap with fossil fuels, making biofuels more competitive [27].

Incentives and regulations are pivotal for biofuel market expansion. These frameworks are expected to significantly boost the biofuel sector in the coming years, promoting investments in sustainable feedstocks and advanced production technologies, which are essential for meeting the growing demand in maritime applications. The use of biofuels is expected to grow due to its potential similarities to marine petroleum, and ease of distribution, storage and bunkering [28]. Figure 3-3 shows the currently projected marine fuel use until 2050 as the industry strives to meet the GHG emissions reduction targets mandated by the IMO.

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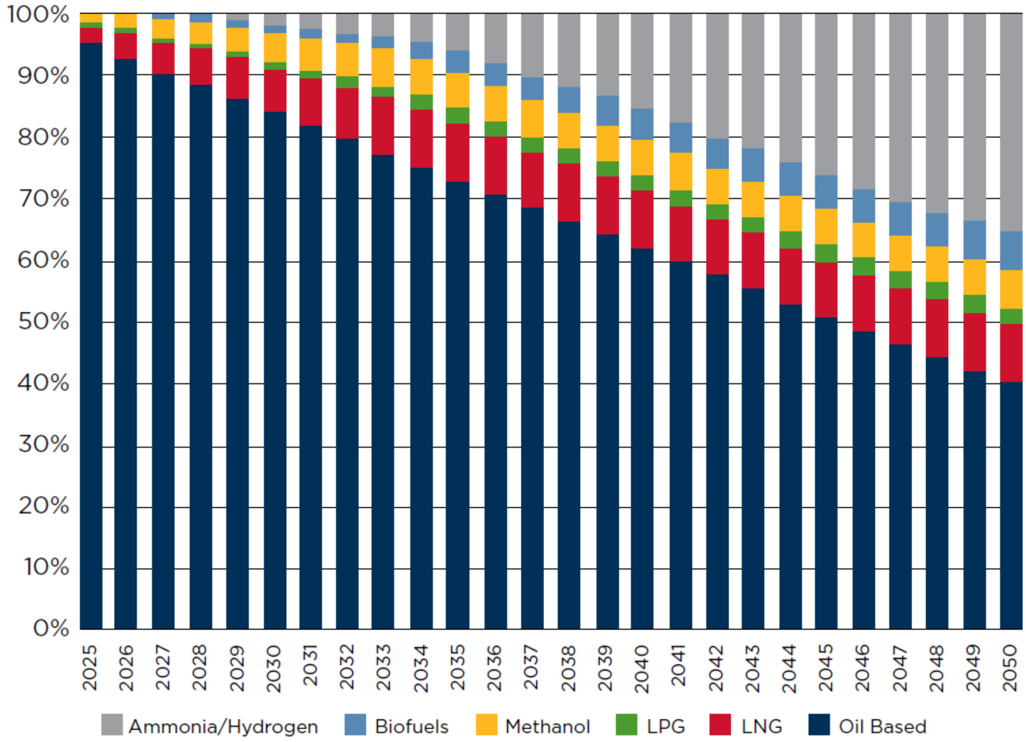

Figure 3-3: Projected Marine Fuel Use to 2050 [28]

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4 USA/CANADA

4.1 General overview of policy drivers

The United States and Canada have implemented significant policy measures to support the development and use of biofuels, driven by a variety of strategic goals including reducing greenhouse gas emissions, increasing energy security, supporting agricultural industries, and stimulating economic growth through innovation in green technologies.

USA

The support for biofuels in the United States aligns with broader policy goals of transitioning to a more sustainable and secure energy system. It is part of the country's efforts to address climate change, promote sustainable development, and foster economic growth through the advancement of clean technologies.

The U.S. aims to lower its net greenhouse gas (GHG) emissions across the economy by 50%-52% from the levels recorded in 2005 by the year 2030 [1]. Biofuels are critical in this effort, offering a sustainable alternative with significantly lower GHG emissions than conventional fossil fuels [2]. This shift is particularly impactful in reducing emissions within the transportation sector, the largest GHG contributor nationwide, which was responsible for around 29% of the country's total emissions in 2021 [3].

Furthermore, the pursuit of energy independence through increased production and use of domestic biofuels reduces reliance on imported oil, enhancing national energy security and shielding the economy from global oil market fluctuations [4]. The biofuel industry also drives economic development by creating employment opportunities in agriculture and manufacturing. Additionally, the push for the development of biofuels technologies spurs innovation and attracts investment in the renewable energy sectors, contributing to job creation and economic growth. [5]

The policy framework, particularly the Renewable Fuel Standard (RFS) [6], is a cornerstone of U.S. support for biofuels. The RFS mandates the blending of renewable fuels with gasoline and diesel, promoting the integration of biofuels into the transportation sector and ensuring a steady market, thus, encouraging investments in biofuel technologies. The Environmental Protection Agency (EPA) has finalized biofuel volume requirements for 2023 to 2025, aiming to support domestic production. This initiative is expected to reduce reliance on foreign oil imports by up to 140,000 barrels per day, contributing to energy independence and supporting rural economy [7]. The U.S. Department of

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Energy (DOE) has also awarded $118 million in funding to accelerate domestic biofuel production [4], highlighting the government's commitment to achieve net-zero emissions by 2050. Furthermore, the Biden Administration has emphasized the role of sustainable aviation fuels (SAF) in reducing emissions from the aviation sector, with federal agencies and industry stakeholders pledging to produce and adopt SAF by 2050.

Canada

Canada's biofuels policies are integral to its comprehensive environmental and economic strategies, aimed at addressing climate change, fostering sustainable development, and moving towards a low-carbon economy. These strategies are further reinforced by the nation's commitment to innovation and job creation within the green technology sectors.

At the heart of Canada's environmental agenda is the recognition of biofuels as a pivotal component in reducing greenhouse gas emissions. This aligns with the country's ambitions under the Paris Agreement to cut emissions by 40-45% from 2005 levels by the year 2030 [8]. By emphasizing biofuels, Canada seeks to diversify its energy portfolio, lessen its reliance on fossil fuels, and enhance energy security. Moreover, the promotion of the biofuel industry serves as a vehicle for economic growth, particularly in rural communities, by generating jobs and fostering innovation.

Canada's commitment to reducing greenhouse gas emissions and fostering economic growth through clean energy technologies is embodied in the Clean Fuel Regulation (CFR), which became law on July 6, 2022. It sets ambitious targets to lower the carbon intensity of liquid transportation fuels, including a significant increase in the use of low carbon-intensity diesel by 2.2 billion liters and in the use of ethanol by 700 million liters by 2030. The CFR, along with the $1.5 billion Clean Fuels Fund, is anticipated to unlock considerable economic opportunities, particularly benefiting biofuel feedstock suppliers such as farmers and foresters, and enabling local fuel producers to compete in the global clean energy market. [9], [10]

Looking forward, the Canadian biofuel industry is on a trajectory of growth, spurred by federal and provincial policies aimed at boosting the use of ethanol, biodiesel, and renewable diesel. The profitability of ethanol and biodiesel has been volatile, influenced by various factors including the pandemic, inflation, and geopolitical events. However, the sector is poised for expansion, supported by emission reduction mandates and the potential for increased canola crush capacity, which is essential for biodiesel and renewable diesel production. Nevertheless, the Canadian biofuel industry must navigate both opportunities and challenges from U.S. policy changes, such as the shift to a

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producer tax credit under the 2022 Inflation Reduction Act, which will impact the biofuel production and export dynamics. [11]

4.2 Policy framework at country level

USA

The United States' biofuels policy framework is primarily supported by the Renewable Fuel Standard (RFS) and the Inflation Reduction Act.

The RFS, initiated by the Energy Policy Act of 2005 and broadened with the Energy Independence and Security Act of 2007, requires the inclusion of a specific volume of renewable fuels into the nation's fuel supply, targeting 22 billion gallons of biofuel (cellulosic, biomass-based biofuel and advanced biofuel) by 2025. The advanced biofuels is estimated at 7.5 billion gallons. This mandate aims to diminish the use of petroleum-based transportation fuels, heating oil, or jet fuel, incorporating stringent sustainability criteria. These criteria necessitate that biofuels achieve a substantial reduction in lifecycle greenhouse gas emissions compared to fossil fuels, encompassing land use restrictions to qualify as renewable under the program (Figure 4-1) [6]. This approach shares similarities with the European Union's emphasis on lifecycle greenhouse gas emissions reductions, albeit with distinct flexibility and implementation mechanisms [12].

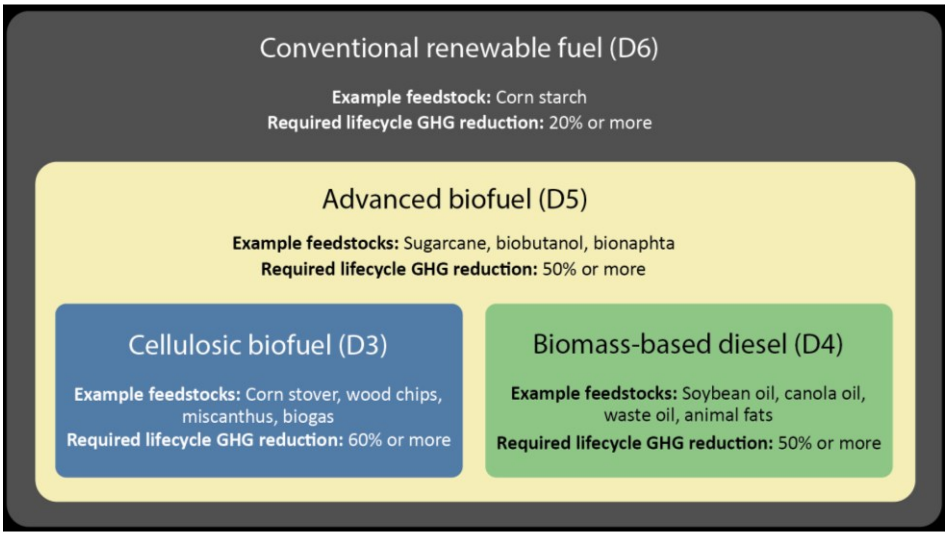

Figure 4-1: Fuel nesting scheme for Renewable Fuel Standard [20]

Enacted in 2022, the Inflation Reduction Act marks a significant stride in climate and energy policy, underlining a robust investment in biofuels. This landmark legislation aims to enhance domestic biofuel production and use, mitigate inflation, and decrease greenhouse gas emissions. Among its provisions, it introduces specific incentives for biofuel production, particularly focusing on lowering the carbon intensity of fuels. These include tax credits for sustainable aviation fuel (SAF) that achieves a minimum 50% reduction in greenhouse gas emissions compared to conventional jet fuel, offering a credit of up to $1.75 per gallon. It also extends the biodiesel and renewable diesel tax credits, providing a $1.00 per gallon for producers through 2024. Additionally, the Act supports the development of feedstock for biofuels, allocating funds for research, development, and deployment activities aimed at reducing the cost and increasing the efficiency of production processes. [13]

In the United States, state-level initiatives complement federal biofuels policies, offering unique approaches to promoting renewable energy and reducing carbon emissions. California's Low Carbon Fuel Standard (LCFS) aims for a 20% cut in transport fuel carbon intensity by 2030 [14]. Similarly, Oregon's Clean Fuels Program (CFP) targets a 10% reduction in transport emissions over a decade, promoting the use of biofuels, electricity, natural gas, and propane as alternatives to gasoline and diesel [15]. Minnesota has been a pioneer with its Biodiesel Mandate, requiring diesel fuel sold in the state to contain a minimum blend of biodiesel with seasonal adjustments. It starts with a B2 blend (2% biodiesel) during colder months to reach a B20 standard (20% biodiesel) during warmer months [16]. Lastly, Illinois currently incentivizes biodiesel use with sales tax exemptions for B14 blends (14% biodiesel or higher) [17] and is planning to rise the required blend to receive the exemption to B17 by 2025 and B20 by 2026 [18].

<u>Canada</u>

Canada's Clean Fuel Standard (CFS) is a critical component of its climate action plan, targeting a reduction in the carbon intensity of fuels used across the country. With the goal of achieving 30 million tonnes of annual GHG emissions reduction by 2030 (30% below 2005 levels), the CFS endeavors to diminish GHG emissions across the lifecycle of fuels while spurring investments in cleaner fuel alternatives and clean technology within the country [19]. More specifically, as outlined in Table 4-1, the CFS mandates a reduction in the carbon intensity of liquid fuels by 10 grams of CO_{2e} per MJ by setting progressively stringent limits until 2030 [20].

Table 4-1: Fuel Carbon-Intensity Limits [20]

Liquid Fossil Fuel	Limit for Each Compliance Period ($gCO2_e$/MJ)							
	2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Gasoline	91.5	90.0	88.5	87.0	85.5	84.0	82.5	81.0
Diesel	89.5	88.0	86.5	85.0	83.5	82.0	80.5	79.0

The CFS applies to producers, importers, and certain distributors of fossil fuels in Canada, establishing them as primary suppliers with a compliance obligation to reduce the carbon intensity of their fuels.

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It also allows for voluntary credit generation by entities engaging in activities that lower the carbon intensity of fossil fuels or produce/import renewable or low-carbon fuels for use in Canada. More specifically, fuel suppliers can comply with the CFS by reducing the carbon intensity of their fuels, utilizing cleaner alternatives, or purchasing compliance credits. However, the standard encourages primarily the adoption of lower-carbon fuels. [19]

The CFS outlines specific criteria for biofuels to be qualified as clean fuels, focusing on lifecycle GHG emissions reductions compared to conventional fuels. It accounts for both direct and indirect land use, elements that are also crucial in the EU's sustainability assessment standards. However, Canada's approach is tailored to its unique environmental, economic, and social context, potentially differing in how indirect effects are calculated compared to the EU framework. The EU's RED is more prescriptive in terms of biofuel types that qualify based on their feedstock, aiming to phase out the ones with a high risk of indirect land use change (ILUC) [12]. Canada's framework, while considering ILUC, provides broader flexibility regarding feedstock selection, prioritizing a more comprehensive reduction in carbon intensity.

4.3 Overview on biofuels production and use

Biofuels are increasingly recognized as crucial for transitioning towards more sustainable transportation, especially regarding aviation and maritime sectors in North America. The USA and Canada have identified biofuels' potential to significantly reduce greenhouse gas emissions associated with these transport modes, leading to a gradual shift in fuel consumption patterns. Despite their environmental advantages, their widespread adoption in aviation and maritime faces hurdles like high production costs, significant infrastructure investments, and limited SAF and marine biofuel supply. Nonetheless, policy support, coupled with technological advances, are expected to address these challenges.

USA

In 2022, U.S. ethanol production reached about 15.4 billion gallons, while the combined production of biodiesel and renewable diesel totalled approximately 3.1 billion gallons. According to the U.S. Energy Information Administration (EIA) [21], detailed statistics are presented in Table 4-2:

Table 4-2: USA biofuels data for 2022 [million gallons]

	Fuel ethanol	Biodiesel	Renewable diesel
U.S. production	15,361	1,622	1,499
U.S. consumption	14,023	1,658	1,718
U.S. imports	69	250	263

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U.S. exports	1,314	238	N/A

In aviation, the USA is pioneering the integration of biofuels. The Federal Aviation Administration (FAA) supports the Commercial Aviation Alternative Fuels Initiative (CAAFI), which aims to facilitate the development and deployment of sustainable aviation fuels (SAF) [22]. These biofuels, derived from renewable resources like waste oils and agricultural residues, have been utilized by several U.S. airlines, demonstrating up to an 80% reduction in carbon emissions over their lifecycle compared to conventional jet fuel [23]. The Department of Defence (DoD) also invests in biofuel technologies to reduce its operational carbon footprint [24].

The Biden Administration has initiated the DOE Sustainable Aviation Fuel Grand Challenge with goals to produce 3 billion gallons of SAF by 2030 and 35 billion gallons by 2050, aiming to cover the annual U.S. aviation fuel demand fully [25], [26]. This is bolstered by the DOE Bioenergy Technologies Office's significant investment in R&D, focusing on developing feedstocks and algae technologies to enhance SAF production and support the aviation industry's net-zero emissions target by 2050 [11].

The aviation industry has made substantial progress with biofuels since the first biofuel-powered flight in 2008, with over 130,000 passenger flights and several military operations utilizing second-generation biofuels for their lifecycle sustainability [27]. IATA projects that SAF could provide about 65% of the emission reductions needed for the industry to achieve net-zero CO_2 emissions by 2050, highlighting the need for a significant increase in SAF production [28].

Maritime applications in the U.S. have seen slower adoption due to infrastructure and regulatory challenges. However, initiatives like the Maritime Administration's (MARAD) investment in research for biofuel-powered vessels and biofuels' inclusion in North American Emission Control Area (ECA) compliance strategies indicate a growing interest in cleaner fuels [29].

Biofuels are considered a promising transitional fuel for the maritime industry, adaptable to existing vessels without the need for modifications. Currently, the most widely available are first-generation biofuels, though they face scalability issues due to competition with food production. Second-generation biofuels, made from non-food feedstocks such as forestry and agricultural residues, are emerging as crucial for shipping decarbonization. [30]

Significant research and development efforts are underway to explore the potential of biofuels for the maritime sector. A collaborative team led by Oak Ridge National Laboratory is investigating the use of energy-dense biofuels such as biocrude and bio-oil to meet new emissions regulations for cargo ships [31]. The Department of Energy's Bioenergy Technologies Office is also investing in the research,

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development, and demonstration of sustainable marine fuels. This effort is critical as international maritime transport is responsible for approximately 3% of global greenhouse gas emissions [32].

Canada

The introduction of the Clean Fuel Regulation (CFR) in 2022 has already influenced Canadian fuel ethanol consumption, which saw an estimated 20% increase in 2022 to 3.4 billion liters. Additionally, the start of commercial operation of Canada's first renewable diesel facility in June 2023 marks a significant milestone in the country's biofuel sector [10], [33]. Canada Energy Regulator's projections highlight an increasing trend in the use of domestic feedstocks, thereby potentially reducing biofuel imports from 50% to as low as 21% in certain scenarios by 2050. The bioenergy supply model employed by the Canada Energy Regulator (CER-BSM) optimizes feedstock use across provinces for different bioenergy types, taking into account factors like feedstock availability and demand for biofuels [34].

Canada's aviation sector mirrors the U.S. in its emphasis on SAF research and development. The Canadian government, through Natural Resources Canada (NRCan), collaborates with industry partners to increase biofuel adoption in aviation, supporting pilot projects and technology demonstrations to validate SAF's environmental and economic benefits [35]. Furthermore, significant federal investments and collaborative projects aim at boosting SAF production. For instance, a notable federal investment of $6.2 million was announced in Manitoba to support SAF development, including a significant project by Azure for front-end engineering and design studies. This project, anticipates creating over 1,500 jobs and producing approximately one billion liters of SAF annually, using Canadian feedstocks like canola and soybean oils [36].

In terms of biofuels use in the maritime sector, Canada's commitment to sustainable marine fuel development is evident through initiatives like the $65 million Clean Ocean Advanced Biofuels Project. This project, aims to produce renewable diesel from agricultural and forestry by-products, marking a significant step towards environmentally sustainable, low GHG emission, and low-sulphur marine fuels. The project is expected to drive Canadian renewable diesel production, reduce imports, foster international market exports, and create more than 150 direct jobs [37]. Additionally, the Port of Vancouver has also engaged in projects assessing biofuel feasibility to lower shipping emissions, signalling a shift towards sustainable maritime operations [38].

4.4 Biofuels market demand

USA

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The United States is one of the world's largest producers and consumers of biofuels, primarily ethanol and biodiesel, which are the two main types of biofuels used in the country. The U.S. produced about 15 billion gallons of ethanol in 2021, a significant part of which was used domestically, with the fuel ethanol consumption amounting to approximately 13.9 billion gallons. Biodiesel and renewable diesel production and consumption have also seen growth, albeit at a smaller scale compared to ethanol. The U.S. biodiesel production stood at around 1.8 billion gallons in 2020, with domestic consumption closely aligning with production figures. [39]. The annual production and consumption of biodiesel and ethanol is presented in Table 4-3.

Table 4-3: Annual Biodiesel and Fuel Ethanol Overview in USA [39]

Year	Biodiesel		Fuel Ethanol	
	Production (trillion Btu)	Consumption (trillion Btu)	Production (trillion Btu)	Consumption (trillion Btu)
2012	126	115	1,120	1,092
2013	173	182	1,127	1,120
2014	163	181	1,213	1,139
2015	161	191	1,254	1,181
2016	200	266	1,306	1,216
2017	204	253	1,349	1,226
2018	237	243	1,361	1,220
2019	220	231	1,336	1,232
2020	232	239	1,181	1,074
2021	218	218	1,271	1,180
2022	207	212	1,299	1,186
2023	217	247	1,321	1,205

Production quantity in Table 4-4 includes total biomass inputs to the production of fuel ethanol, biodiesel and renewable diesel fuel. Beginning in 2014, it also includes production of other biofuels. Consumption quantity in Table 4-4 includes fuel ethanol (minus denaturant), biodiesel, renewable diesel fuel and other biofuels, plus losses and co-products from the production of fuel ethanol and biodiesel.

Table 4-4: Total annual biofuels production and consumption in USA [39]

Year	Production (trillion Btu)	Consumption (trillion (Btu)
2012	1,936	1,899
2013	2,000	2,026
2014	2,135	2,099
2015	2,201	2,185
2016	2,329	2,333
2017	2,407	2,364
2018	2,471	2,355
2019	2,432	2,376

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2020	2,194	2,136
2021	2,374	2,331
2022	2,511	2,433

The future demand for biofuels in the USA is subject to various factors, including federal policies, technological advancements, and global energy market trends. The Inflation Reduction Act of 2022 and potential adjustments to the RFS could significantly impact future biofuel demand. Future demand for ethanol could be influenced by changes in fuel economy standards, electric vehicle adoption rates, and modifications to the RFS. Ethanol production is projected to remain stable or grow slightly, as it continues to be an essential component of the U.S. energy mix for octane and oxygenate in gasoline blends [40]. Demand for biodiesel and renewable diesel is expected to rise, driven by the increasing demand for cleaner transportation fuels and the expansion of low carbon fuel standards (LCFS) in states like California. The growth of the renewable diesel sector, in particular, is anticipated to be robust due to its ability to directly substitute for diesel fuel without the need for blending. [41]

Looking forward, the biofuels market is projected to grow from $163.86 billion in 2023 to $176.59 billion in 2024, at a CAGR of 7.8%. This growth is attributed to energy security concerns, volatile oil prices, and government incentives. By 2028, the market is expected to reach $240.55 billion, growing at a CAGR of 8.0%, driven by renewable energy targets, advancements in feedstock production, rising public awareness, and emerging economies' adoption. [42]

Focusing on aviation sector, IEA's report on Renewables 2023 analyses three cases. In the main case, incentives such as IRA credits, the Renewable Fuel Standard’s Renewable Identification Numbers (RINs), and Low Carbon Fuel Standard (LCFS) credits help raise US biojet fuel demand to nearly 2 billion litres by 2028. These credits, potentially worth near USD 1/litre, narrow the price gap with fossil jet fuel. In the accelerated case, biojet fuel expand to cover nearly 3.5% of global aviation fuels – up from 1% in the main case. As highlighted in Figure 4-2, the United States are at the forefront of this growth, propelled by strong policy support. In the Net Zero Scenario, biofuels make up 8% of shipping fuel and 10% of aviation fuel by 2030, up from nearly zero in 2022 and well above accelerated case projections. [43]

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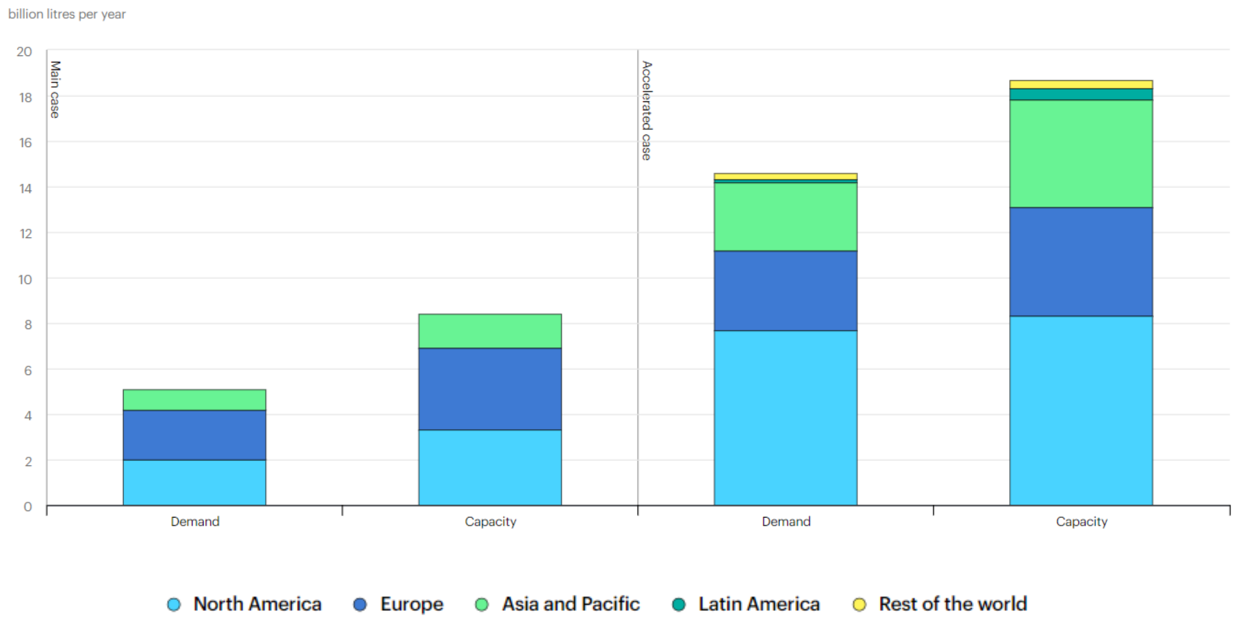

Figure 4-2: Biojet fuel five-year growth in demand and capacity additions [billion liters per year], main and accelerated cases, 2023-2028

Canada

Canada's biofuel sector primarily revolves around ethanol and biodiesel, with government policies like the Renewable Fuels Regulations supporting its development [44]. Canada's ethanol production has been steadily increasing, with the country producing approximately 1.8 billion liters of ethanol annually. The federal mandate requires gasoline to contain an average of 5% renewable content, which has been a significant driver of domestic ethanol consumption. The biodiesel market in Canada is smaller compared to ethanol but has been growing due to the federal mandate for diesel fuel to contain a 2% renewable content. Annual biodiesel production capacity is estimated to be around 500 million liters. [45]

Table 4-5: Annual Biomass-based diesel and Fuel Ethanol Overview in Canada [45]

Year	Biomass-based diesel		Fuel Ethanol	
	Production (trillion Btu)	Consumption (trillion Btu)	Production (trillion Btu)	Consumption (trillion Btu)
2012	3	21	38	56
2013	5	29	38	64
2014	12	31	39	68
2015	10	23	38	69
2016	15	13	38	63
2017	14	25	39	70
2018	10	25	39	67
2019	12	27	42	69
2020	15	30	38	62
2021	14	28	39	65

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2022	3	21	38	56

The future demand for biofuels in Canada is influenced by several factors, including environmental policies, the Clean Fuel Standard (CFS), and the global push towards reducing carbon emissions. The demand for ethanol is expected to continue growing, especially with the implementation of the CFS, which aims to reduce the carbon intensity of fuels used in Canada. The CFS, set to be fully implemented by 2030, could significantly boost ethanol use as a low-carbon alternative to traditional gasoline. The demand for biodiesel and renewable diesel is also projected to rise under the CFS. The push for lower carbon intensity fuels and the growth in renewable diesel production capacity are likely to increase biodiesel's market share in the coming years. [46]

4.5 Practical consequences for market actors

The biofuels policy framework in both the USA and Canada plays a pivotal role in shaping the landscape for advanced biofuels developers and producers. These frameworks are not just regulatory measures but also serve as catalysts for industry growth, innovation, and sustainability.

In the USA, the Renewable Fuel Standard (RFS) is a cornerstone policy driving the demand for biofuels. The RFS mandates the blending of renewable fuels with gasoline and diesel, setting specific volume requirements for different categories [6]. This mandate not only ensures a market for biofuels but also encourages the development and commercialization of advanced biofuels technologies by guaranteeing a certain level of demand. Moreover, the RFS's structure incentivizes the production of biofuels with higher greenhouse gas (GHG) emissions reductions, favouring advanced biofuels over conventional ones. Additionally, the Inflation Reduction Act in the USA introduces tax credits and funding opportunities for renewable energy projects, including biofuels [13]. These financial incentives are designed to lower the cost of producing advanced biofuels and encourage further investment in biofuels infrastructure and research, thereby accelerating the sector's growth.

In Canada, the Clean Fuel Standard (CFS) mirrors the ambition of the RFS by aiming to reduce the carbon intensity of fuels. Set to be fully implemented by 2030, the CFS mandates a reduction in the GHG intensity of fuels used across various sectors, including transportation [19]. This policy framework is significant for advanced biofuels developers and producers, as it creates a market demand for lower-carbon fuels, thereby encouraging the shift away from fossil fuels. The CFS is expected to drive the adoption of biofuels by requiring fuel suppliers to gradually decrease the carbon intensity of their products, offering credits for exceeding reduction targets, and potentially imposing compliance payments for falling short.

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Both countries also support the biofuels industry through various research grants, investment in technology development, and pilot projects [47]. These initiatives provide crucial support for overcoming technical and economic barriers to biofuels production, particularly for advanced biofuels that are still reaching commercial viability.

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5 Brazil

5.1 General overview of policy drivers

Brazil has played a pioneering role globally in the production and implementation of biofuels. The country has successfully integrated biofuels mandates, financial incentives, and sustainability requirements to expand the availability of safe and affordable biofuel resources. The start of ethanol blending mandates dates to 1975 with the ProAlcohol program. Over the years, the mixing requirements have progressively increased, currently reaching 27% in terms of volume. Notably, approximately 90% of Brazil's light-duty vehicle fleet is made up of flexible vehicles, which allow consumers to choose between gasoline and ethanol. This gives Brazilian consumers the flexibility to opt for higher ethanol blends when ethanol prices are advantageous. As of 2022, the total ethanol blending rate has reached 34% in terms of energy [1].

Following this experience of implementing biofuels, Brazil's National Biofuels Policy was published in 2016 and named RenovaBio [2], which focuses on promoting the proper expansion, production and use of biofuels in Brazil's national energy matrix.

The Programme is based on three main pillars: annual **CO_2 reduction (CO_2/MJ),** adequate **certification of biofuels** and the creation of Decarbonization Credits (**Cbios).**

This last part represents an important part because it is a new market model where each **Cbios** represents one metric ton of CO_2 that is saved by using biofuels compared to fossil fuels. This measure is intended to build an environment where the producers of these biofuels are the greatest beneficiaries, as a market oriented towards them emerges.

As a novelty in 2023, a new bill "Programa Combustível do Futuro" appears [3] where new main objectives are established, such as:

1- Propose measures for the integration of RenovaBio in conjunction with other sustainable programs such as ROTA 2030, PBE Veicular, PNPB (National Program for the Production and Use of Biodiesel) among others.

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2- Propose a methodology for the well-to-wheel (LCA) to assess emissions from different modes of transport.

3- New studies to expand the use of sustainable and low-carbon fuels, fostering research, development and innovation. The integration of sustainable aviation kerosene, as well as marine biofuel, into the energy matrix is sought, in addition to the use of carbon capture and storage technologies associated with the production of sustainable and low-carbon intensity fuels.

It should be noted that both RenovaBio and the Combustível do Futuro Program are initiatives implemented only in the field of biofuels, since in a more general context, several initiatives and projects have been compiled that promote Brazil to achieve sustainability, social and economic objectives that are included in Table 5-1.

Table 5-1 Brazil policy summary

Policy	Year
RenovaBio[2]	2016
Ten-Year Plan of Energy Expansion 2032 [4]	2022
2023-2025 Working Plan of the National Hydrogen Program (PNH2) [5]	2022
Action Plan: Zero deforestation by 2030 (5th phase) [6]	2023
Light for all programme [7]	2023
Programa Combustível do Futuro [3] (Fuels of the Future)	2023

Each and every one of them is integrated within the framework of sustainability and aims above all to improve the country's energy matrix. Starting with the "Ten-Year Plan for Energy Expansion 2032" that establishes predictions of both production and consumption over a 10-year period, this report includes several visions and provisional goals that the country has in different sectors, such as energy and energy efficiency or the one of interest such as the supply of biofuels.

On the other hand, policies such as the protection of the Amazon to stop its deforestation "Zero deforestation by 2030 (5th phase)" in which it is intended to reach a balance where deforestation is fully controlled while an implementation of the bioeconomy arises to be able to take advantage of the bioresources that the Amazon provides, adds value to the future matrix of biofuels where an adequate

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management of the forest territory comes to promote production generating greater availability of feeds for the total production of biofuels.

In the field of hydrogen, Brazil has set out to enter the market and to this end launched the three-year National Hydrogen Plan to establish ambitious goals to establish pilot plants in different regions of Brazil by 2025, to try to consolidate Brazil as a large competitive producer of hydrogen globally.

Finally, mention should be made of a major social initiative that, through renewable sources, seeks to supply electricity to rural populations who live in remote regions of the Amazon and do not have access to distribution from the public electricity grid thanks to this government initiative around 10 million people have benefited in multiple regions.

5.2 Policy framework at country level

RenovaBio incorporates sustainability criteria that are integral to its functioning. These criteria are designed to ensure the reduction of greenhouse gas emissions and adherence to robust environmental and social standards. Biofuels producers seeking to participate in the RenovaBio program must obtain certification from the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP). This certification process is essential for producers to generate decarbonization credits (CBios), adding an economic incentive to environmentally friendly practices.

The sustainability criteria outlined in RenovaBio draw inspiration from globally recognized standards, particularly the principles of the Roundtable on Sustainable Biomaterials (RSB) and the European Union's Renewable Energy Directive (RED II). This alignment with international benchmarks is significant, positioning Brazilian biofuels as meeting high environmental and social standards on a global scale.

The implications of these sustainability criteria are twofold. On one hand, they ensure that biofuels produced in Brazil meet the expectations of international markets, enhancing the acceptance of Brazilian biofuels globally. On the other hand, these criteria may pose challenges for biofuel producers, as they require compliance with strict standards and navigating complex certification processes. This could impact the competitiveness of Brazilian biofuels in the global market, especially if other producers face less stringent requirements. Some studies suggest uncertainty within the program, with examples such as the possible ambiguity of policies that, if not clearly defined or properly communicated with stakeholders, could lead to various interpretations, strategies, and hidden investment decisions by industry players. Another example could be delays in the publication of

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guidelines for the certification of carbon reduction credits (CBIOS) under the RenovaBio framework, which could slow down the participation of biofuel producers in the program and thereby create uncertainty among investors and hinder the development of a robust CBIOS market, impacting the overall effectiveness of the policy. Lastly, another example could be the insufficient resources for supervising and enforcing RenovaBio requirements. Without effective enforcement mechanisms, there is a risk that some biofuel producers may not meet sustainability criteria, which would challenge the integrity of the program.

Despite these potential challenges, Brazil's commitment to sustainability in its biofuels policy framework reflects a broader dedication to environmentally and socially responsible practices. RenovaBio has proven successful in promoting the expansion of biofuels production and usage in Brazil, establishing the country as a global leader in the biofuels industry. The program serves as a testament to Brazil's proactive stance in aligning its biofuels sector with international sustainability standards, contributing to a cleaner and more sustainable global energy landscape. In this scenario appears the **RenovaCalc** [8] system, that works as a calculator for the biofuel production unit's environmental performance within the RenovaBio program's scope. The instrument assigns an Energy-Environmental Efficiency Score (EEA), assigned by Embrapa [9], to the biofuel producer based on information on its production process and data on the cultivation of the biomass used to produce the biofuel. The note composes the factor for issuing Decarbonization Credits (CBIOS), which can be negotiated later by the biofuel producer.

On the other hand, the entrance of the "Programa Combustível do Futuro" and the intention to bring together all sustainable policies within one framework, it is proposed that RenovaBio be integrated into this new, more general program in order to accelerate internal management. To this end, the technical committee of Fuels of the Future specifies the creation of subcommittees to improve communication and transmission of knowledge between the different energy matrices in the national environment, where their structure is represented in the Figure 5-1, where the 6 subcommittees and their main objectives appear.

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With this structure, the program addresses several issues that converge towards the decarbonization of the energy matrix of transport, the industrialization of the country and the increase in the energy efficiency of vehicles.

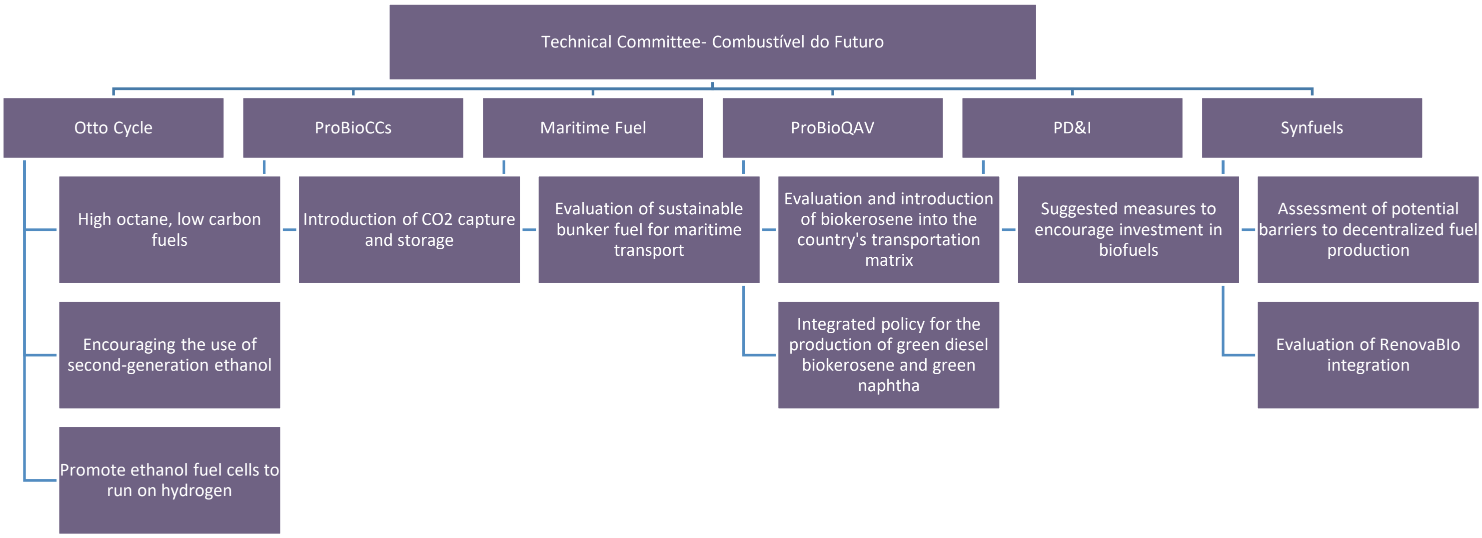

Figure 5-1 . Distribution of the Combustível do Futuro Committee

In the field of biofuel blending, an expansion of the use of anhydrous bioethanol in gasoline is proposed, where currently the standard blend is 27.5% and a maximum of 35% is to be reached if the technical feasibility is demonstrated. On March 17, 2023, Brazil's Ministry of Mines and Energy increased the biodiesel (B10) blending mandate from 10% to (B12) 12% that would become effective in April of that same year, setting new targets for the consecutive 2024 B13, 2025 B14, B15 2026 and the final goal that is set is the B20 is intended to be implemented in 2030, that is, 20% of the biofuel blend in diesel. [10]

According to ProBioQAV, the production and use of sustainable aviation fuel will be encouraged, where air operators are required to reduce CO2 emissions by 1% from 2027, reaching a reduction of 10% in 2037. This reduction will be achieved by gradually increasing the blend of SAF with aviation fossil kerosene (a volumetric percentage of SAF is not established). However, with the draft legislation **PL 1873/2021** which includes a gradual mandatory consumption of biofuels both in blending with diesel and aviation paraffin from 2027 to 2030 with 2% in the first year gradually increased by 1% until reaching 5% in 2030, although the amendments to the bill propose that the percentage be maintained at 1% given that the country **does not** yet produce these biofuels.

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This draft legislation is in line with Brazil's international participation in CORSIA, which promotes the use of SAF and carbon offsetting.

On the maritime sector, within the IMO, to which Brazil is a member, programs were established to achieve sustainable objectives, where the main goal is to establish a new limit for sulfide emissions of 0.5% in general areas and 0.1% in controlled areas.

To achieve these goals, several alternatives have been evaluated, which in the case of Brazil, as has been done with aviation, has also created a “marine fuels” subcommittee that is part of the “Fuels for the Future” program.

To analyze the scenarios that may occur in this sector, an analytical model is used, Brazilian Land Use and Energy Systems (BLUES), which is the national “Integrated Assessment Model” they use, where the interactions between different matrices are considered.

To try to understand and summarize the most important biofuels policy in Brazil compared to the European one, a comparative Table 5-2 has been made where it is summarized largely in which these policies agree and differ in addition to their criteria.

Table 5-2 Comparison between RenovaBio and RED III (Own elaboration)

Aspects	RenovaBio	RED III – Directive
Objectives	It seeks to contribute to the Paris Agreement by promoting the expansion of biofuels in the energy matrix and reducing GHG emissions in the fuel market.	Promotion of energy from renewable sources, including targets and sustainability criteria for transport fuels, contributing to the Paris Agreement.
Renewable Raw Materials	Biomass types and biofuel routes, including new biomass types that are constantly updated under RenovaCalc.	Sustainable biomass, specific list of low ILUC risk feedstock for advanced biofuels production (“Annex IX-A)
Vision & Goals	Accelerate the biofuel matrix promoting the reduction of their GHG emissions in the total energy matrix by 37% (below 2005 levels) by 2025 and 43% by 2030.	Increase the share of renewable energy in the total transport matrix by 29% by 2030; combined advanced biofuels and RFNBO target of 5.5% by 2030 (however, due to various multiple counting rules, lower physical quantities needed)
Biofuel Scope	It includes biofuels in its expansion strategy in the energy matrix.	Biofuels, Advanced Biofuels, Renewable Fuels of Non-Biological Origin (RFNBOs) (E-fuels)

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Land Use	Promoting land protection and sustainable agricultural practices	Sustainable land use, avoiding areas of high biodiversity, list of low ILUC feedstock for advanced biofuels.
Minimum Support Price	Support from the National Biofuels Fund in addition to the integration of the Cbios system	No, the EU sets only targets, however, Member States are allowed to provide financial support to a certain degree. e
Financial Initiatives	Consideration of subsidies and support from the National Biofuels Fund.	Investment and R&D subsidies; but no production support.
Quality Standards	RenovaCalc, based on the Virtual Sugar Cane Biorefinery (VSB) model, a type of LCA, estimates carbon intensities. Maintaining strict standards of traceability and sustainability.	Strict standards for biofuels with stringent traceability and sustainability
Import and export of biofuels	Controlled importation, avoiding high costs of domestic production of biofuels.	Import permitted, if compliant with RED III sustainability criteria
Sustainable approach	It emphasizes inedible raw materials, waste, and degraded land to ensure sustainability.	Set of RED III sustainability criteria including GHG savings, protecting wetlands, old grown forests, biodiverse grassland, LULUCF criteria, sustainable harvesting,
Institutional mechanisms	RenovaCalc, developed by Embrapa, the University of Campinas and Brazil's National Bioenergy Laboratory (LNBR), estimates carbon intensities and generates decarbonization credits (CBIOS) by comparing GHG emissions between biofuels and their fossil counterparts.	Compliance with sustainability criteria to be verified by EC approved voluntary sustainability schemes or national sustainability schemes.

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5.3 Overview on biofuels production and use

The current biofuels scenario, together with the proposed policy measures, project bullish scenarios in the biofuels market, giving importance to the feeds that predominate mainly in the country. As the world's second-largest producer of ethanol, the country, along with its transportation measures, has a high domestic demand.

Therefore, in order to expand this biofuel matrix, new technological routes for the production of these synthetic biofuels are analysed, focusing on new logistical routes for the use of new feeds, such as MSW using gasification or mentions of electrolysis for the production of e-fuels.

For now, there are only 339 biofuel plants that use this system, 283 sugarcane-based ethanol plants, 6 corn-based sugarcane plants, one cellulosic ethanol plant, 5 corn-only plants, 38 biodiesel plants and 6 biomethane plants. [11]

The main source of biofuel production in Brazil is ethanol, which mainly comes from the sugar or corn sector. Figure 5-2 shows the evolution of this main biofuel in Brazil.

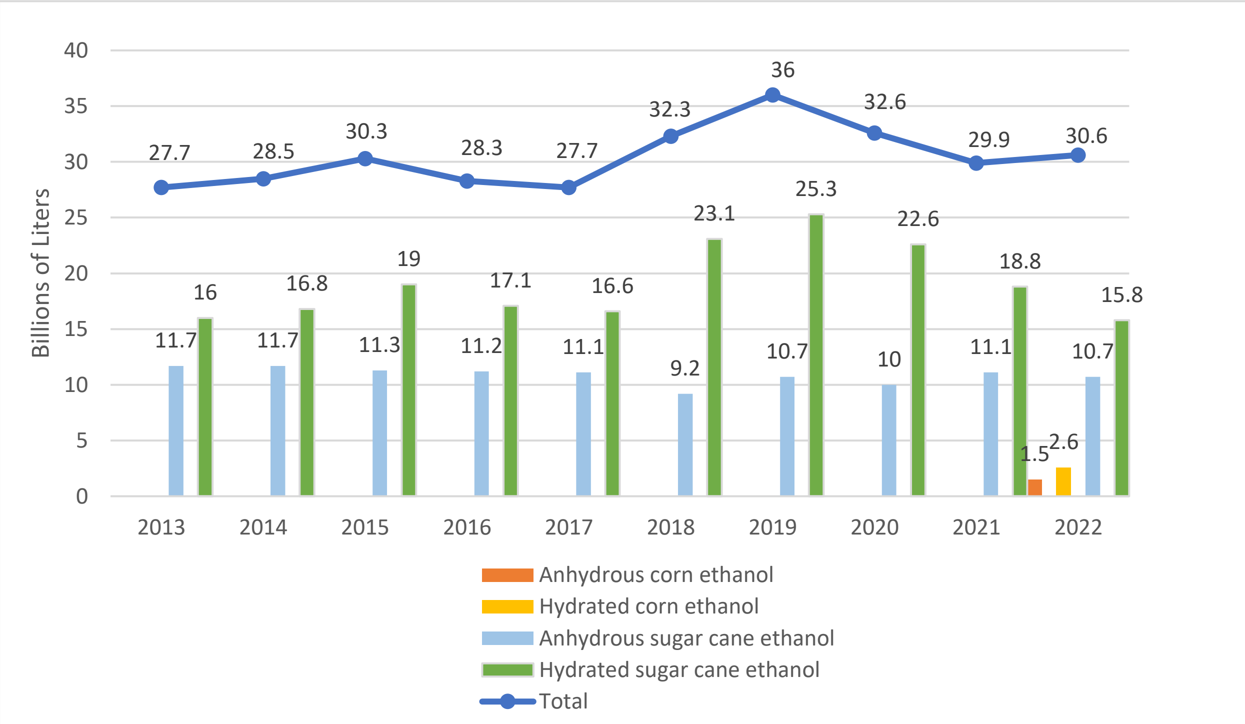

Figure 5-2 Production of hydrated and anhydrous ethanol from sugarcane and corn.

The use of ethanol as a fuel in Brazil varies depending on the type of vehicle used, so hydrated predominates over anhydrous because the fleet of vehicles that can use anhydrous is smaller, so the government encouraged both production and consumption through the flex-fuel vehicle policy.

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In the **Figure 4** We can observe the amount of biodiesel that has been produced over the years, seeing how little by little Brazil is reaching the proposed objectives already discussed above, also in the following **Figure 5**, we see what is the largest representative feed in the creation of biodiesel.

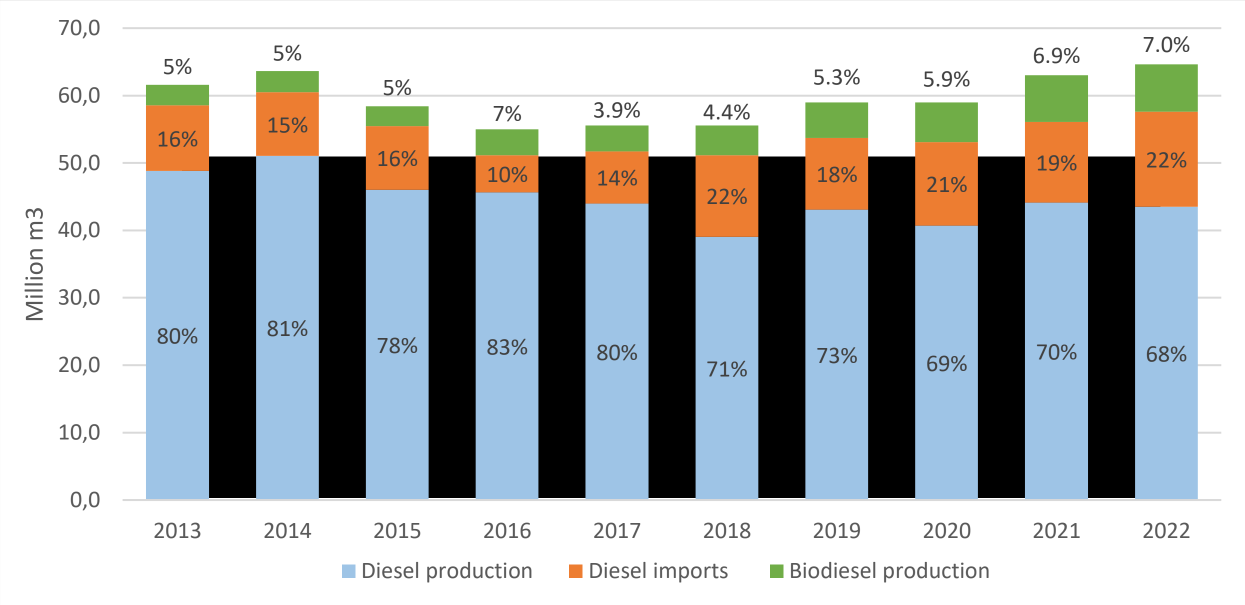

Figure 5-3 Diesel and biodiesel production

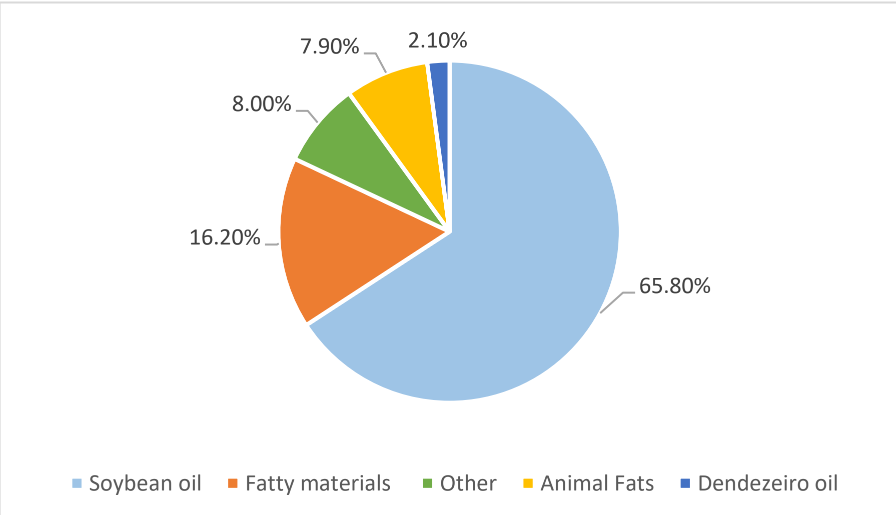

Figure 5-4 Percentage contribution of soybean oil, fatty materials, others, animal fat and Dendezeiro oil feeds to produce biodiesel.

In this case, and given the trajectory shown in recent years, the trend is for soybeans to continue to be one of the main inputs used for the production of biodiesel for a long time, although other raw materials are increasingly appearing in this market, such as various fatty materials such as palm oil and used oils. Given the need to meet the increases foreseen in the mandates, there is a need to diversify the mix of inputs. For more data on the processing of these raw materials, you can visit the data of the Barsileña Association of Vegetable Oil Industries. [12]

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In the SAF scenario in 2022, the Petrobas company, through the BioRefino program, intends to promote the production of state-of-the-art sustainable biofuels such as Diesel R (5% vegetable oil mixed with fossil fuel), all this in the 4 main refineries (REPAR, RPBC, REPLAN, REDUC, PETROBRAS).

In line with the approved technological routes to produce sustainable aviation kerosene, and the most promising availability of food in the country (Attalea speciosa, sugarcane, macaúba fruit (*Acrocomia aculeata),* eucalyptus and soybean) there are industrial and economic challenges for SAF to be competitive against fossil kerosene.

Although no significant SAF production is projected over a 10-year time horizon, concrete projects have been announced for the industry, such as in 2022, Petrobras announced a project to implement a production of 2.2 million barrels per year at the refinery (RPBC) and the same value for 100% renewable diesel from the processing of up to 790 thousand tons of raw material per year. With what has been said above about the BioRefino program, it is intended to create a consortium in conjunction with BBF (Brasil Biofuels) to produce SAF and HVO from **palm oil**, with a production capacity of 500 thousand m3/year to be shared equally between both biofuels.

There are two known pilot cooperation projects between Brazil and Germany. In which the first is an initiative for industrial learning and the second where the private sector is also introduced to study the installation of a mobile pilot plant to produce hydrogen and SAF from non-biogenic matter (RFNBO's). [13]

In the maritime sector, no type of dedicated biofuel is being produced, although initiatives have been proposed where both the production and the use of biofuel in the maritime sector are projected.

To summarize the production of biofuels, the following **table 5** is presented based on statistical data:

Table 5-3 Biofuel production in Brazil[4]

Year	Biodiesel (1000 m^3)	Bioethanol (1000 m^3)
2010	2.4	28.0
2011	2.5	22.9
2012	2.8	23.8
2013	2.9	27.5
2014	3.4	28.2
2015	3.9	30.0
2016	3.8	28.7

[4] Production data is provided by Agência Nacional do Petróleo, Gás Natural e Biocombustíveis. [14]

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2017	4.3	28.6
2018	5.4	33.0
2019	5.9	35.3
2020	6.4	32.7
2021	6.8	30.0
2022	6.3	30.7
2023	7.15	35.4

5.4 Biofuels market demand

The demand for biofuels in Brazil, a dynamic and evolving scenario driven by the previously mentioned government and strategic policies to address environmental and energy challenges. In the Figure 5-5 belonging to the national demand [15], we can see how Brazil projects its total demand (blue line), which based on the year 2022 increases annually by 4.3%, reaching approximately 25,000 m^3/d that would be represented as 9,125,000 m^3/year in 2032 of aviation kerosene.

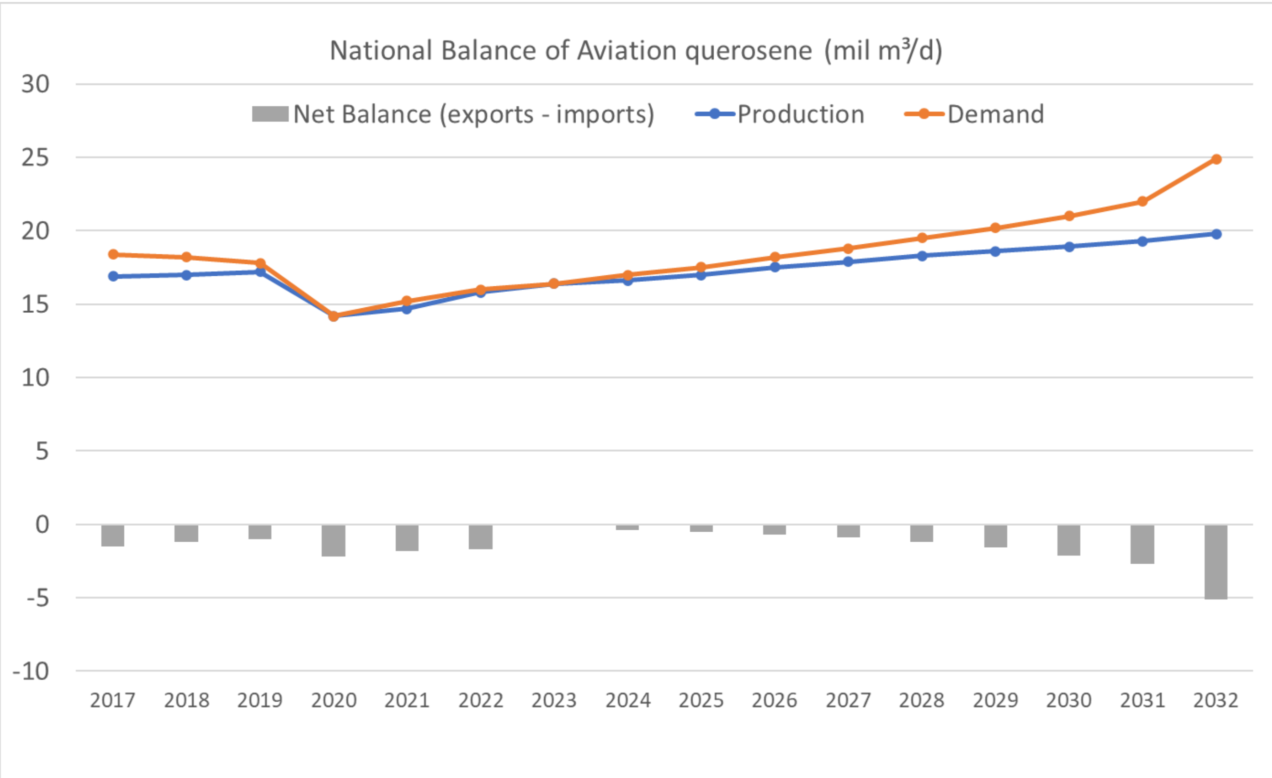

Figure 5-5 Domestic demand for aviation kerosene in the coming years

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With this forecast of demand in the aviation sector and with the comments provided in the supply of biofuels of the same plan, it is said that Brazil would have the capacity to generate about 200,000 m^3 of SAF per year, which would represent 2.19% of the market rate of this sector. This figure varies from the previous Ten-Year Energy Expansion Plan 2031 [16] where a demand of 130,000 m^3 of SAF was established, representing 1.4% of the total market rate of the sector.

If the mandatory target of the CORSIA program is the use of 1% SAF by 2027 and with the forecast that Brazil in that year will be demanding about 7,300,000 m^3/year of aviation kerosene, it would have to produce 73,000 m^3/year of SAF.

In the Table 5-4 It represents the announcements and operations of the places that are going to produce renewable fuels soon, highlighting that of all these facilities they are not going to be dedicated to the production of SAF with the exception of the SENAI pilot plant [17] that is one of the first pilot plant to produce SAF, which produces a synthetic crude oil of the order of 5 liters per day that converts into 1,825 m^3/year, is the only operational pilot plant that intends to transform the product they have into SAF pending the relevant certifications. It has to be considered that all this forecast is in continuous evolution and suspect to changes.

Table 5-4 Forecast of the production of SAF and other biofuels in Brazil.

Announcement	Operativeness	Projection (m^3/year)	Projection (Mtep/ year)	Estimated projection of SAF (Mtep[5]/year)[6]	Feeding	Company	Process[7]
06/09/2023	2023	1,825	0.00155	0.00155	Glycerine	-	06/09/2023
13/04/2022	2025	500,000	0.425	0.2125	Palm oil	Brazil biofuels	HEFA
29/01/2024	2026	1,000,000	0.85	0.425	Mix of palm oil, soybean, and macauba oil	Acelen	HEFA
09/07/2024	2028	870,500	0.7399	0.370	UCO[8] and mix of vegetal oil	Petrobras	HEFA

[5] An 850 kg/m3 density of the crude has been used.
[6] This estimation is based on the 50% of the total production capacities of the industries is supposed to be for SAF only.
[7] HEFA: hydrotreated esters and fatty acids, ATJ: Alcohol to jet
[8] UCO: Using cooking oil.

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					and an animal fat.		
09/07/2024	2028	1,102,700	0.9373	0.468	UCO and mix of vegetal oil and an animal fat.	Petrobras	HEFA
21/03/2024	-	380,000	0.323	0.161	Second generation ethanol	Energis 8 Brasil	ATJ[9]

For the maritime issue, no information is provided beyond what has already been commented on the IMO.

Through the report and in conjunction with the information provided by both the government of Brazil and the ICAO we can access to a map [18] where the future SAF production facilities are compiled, so we can get an idea of whether the objectives will be fulfilled in key years such as 2027 where members who meet certain requirements, which Brazil do, will already have to participate in CORSIA, having to use 1% SAF on their commercial flights.

In addition, in the Figure 5-6, it is possible to visualize how Brazil intends to strategically implement the SAF production plants close to the existing biodiesel and ethanol plants, since in the end the logistics chain provided by both results in an added value to the supply chain of the new facilities, it is

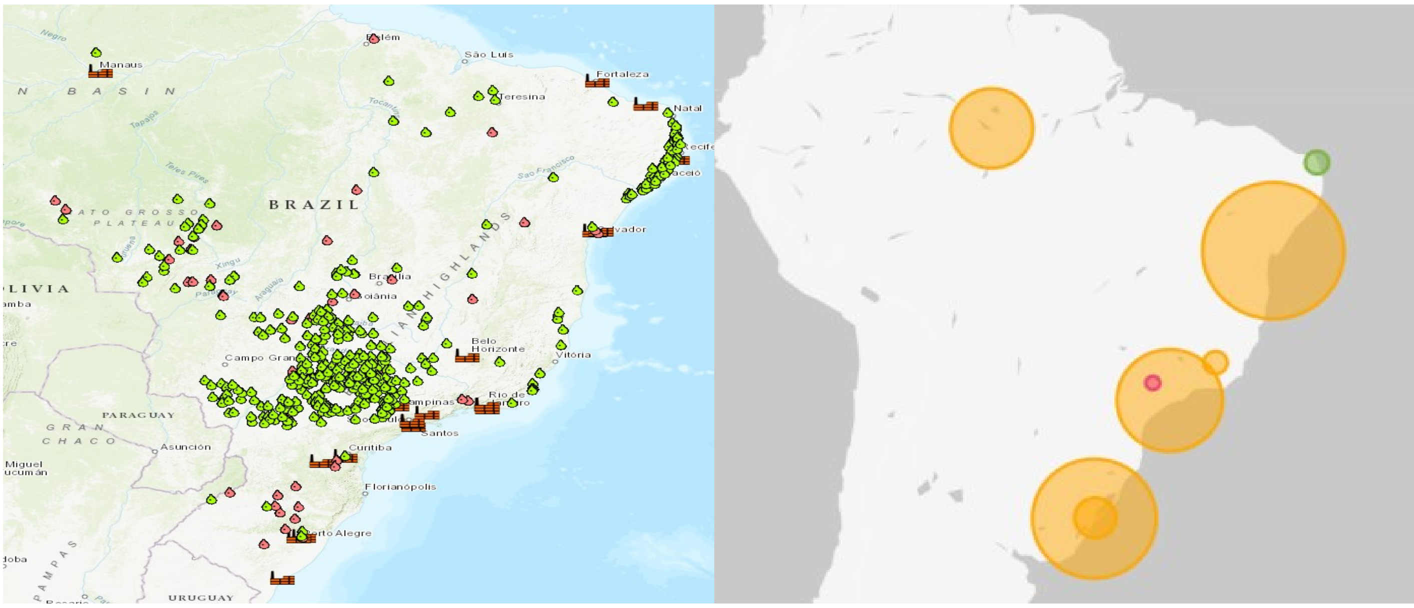

Figure 5-6 Biofuel production Facilities and Future SAF Production Facilities.

[9] ATJ: Alcohol to jet.

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also seen the fact that the already existing refineries will be the main producers and developers of the technologies necessary for the production of SAF. [19]

In the maritime sector, we turned to the subcommittee formed in Fuels of the Future, where in its report [20] establishes a strategic plan for the use of marine biodiesel, in the Figure 5-7**,** where the orange part represents the projected biodiesel demand and the grey part the total biodiesel production capacity, it can be seen that over the years from the surplus of biodiesel, a certain amount of biodiesel can be produced for marine use.

According to these forecasts, it would be said that the use of biodiesel for maritime use would reach around 25% of the total biodiesel that is being produced, indicating that they have the capacity to develop in this sector, but measures are not yet being taken for this sector.

Specify that currently the existing regulations for the use of marine biodiesel (FAME) are 7% by volume in marine diesel. Alternative scenarios involving changes in the percentages of blending with used oils then entail changes in ISO regulations and national standards. [20]

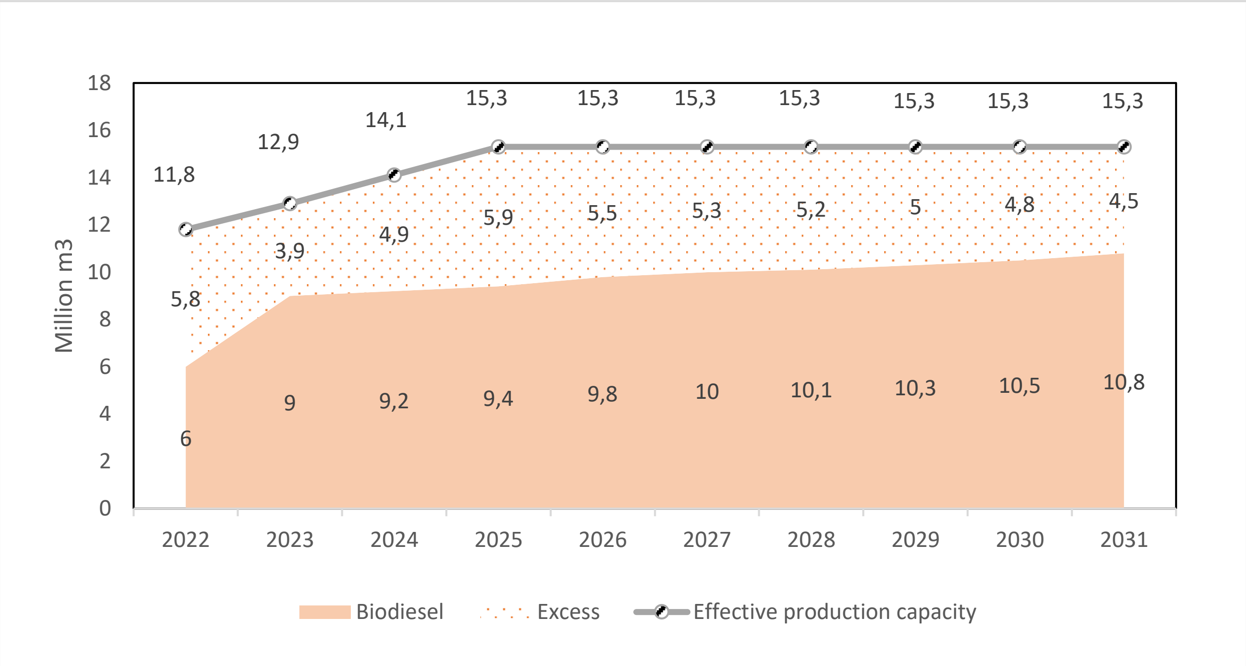

Figure 5-7 Total, Biodiesel Production Capacity (millions of m3)

Figure 5-8 shows how much the demand for biodiesel varies, if the percentage of blending of biodiesel with marine fuel were to increase with the change in regulations in the sector, where if the best-case scenario in which regulations allow up to a blend of 30% biodiesel were to occur, the production capacity would fully cover the demand for marine biodiesel that would be needed.

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In the case of marine biofuels, the Brazilian delegation has expressed the opinion of using the model of the European directive (RED II) or the American directive (CARB) on sustainability criteria, although it understands that it is essential to ensure that alternative fuel routes do not cause adverse GHG leaks throughout the life cycle due to marine fuels and their secondary effects on food security. [20]

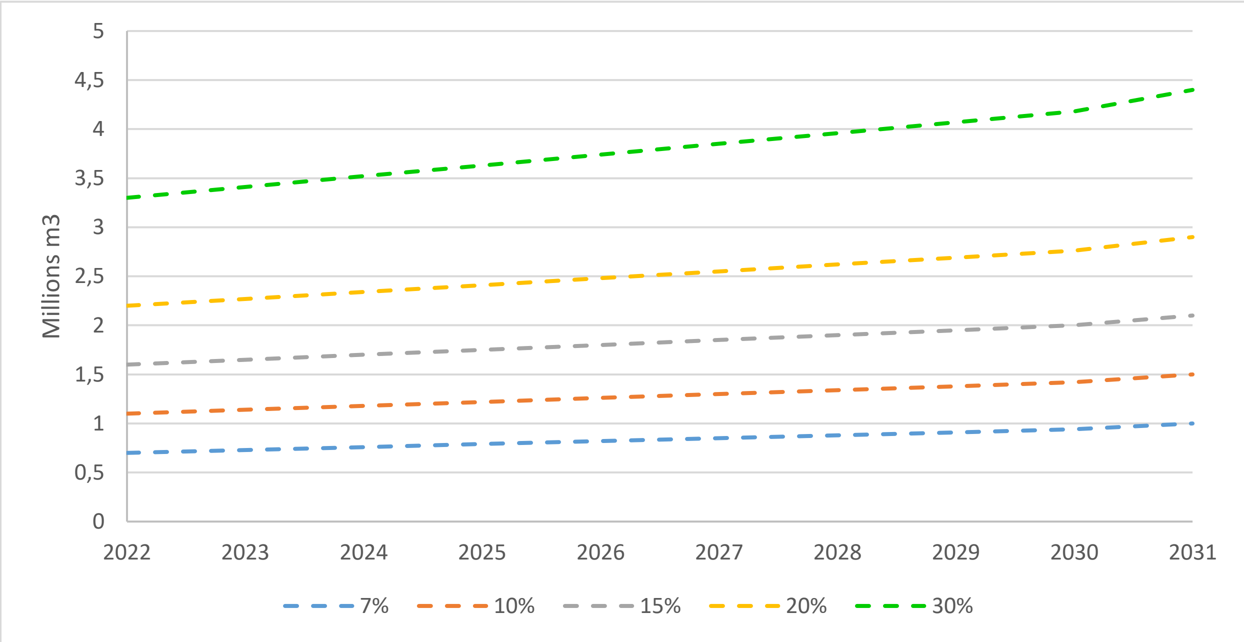

Figure 5-8 Projection of the demand for biodiesel blends in marine diesel.

It is expected that by 2026 marine diesel and low-sulphur oil will still supply almost the entire maritime fleet. In addition to the development of projects for the use of hydrogen and ammonia in ships and the growth of tests on ships with methanol and biofuels.

By 2030, the availability of low-emission alternative fuels is expected to increase by phasing out fossil fuels. A small portion of the fleet will be powered by ammonia and hydrogen. By 2050, a large portion of ships will use low- or carbon-neutral fuel.

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5.5 Practical consequences for market actors

Key stakeholders that are involved in the RenovaBio project, within the ProBioQAV segment, include airlines, aircraft manufacturers, associations, fuel producers/distributors, universities, government entities, international partners, certifiers, and consultants.

For market players, the involvement of these players has several practical consequences:

- Regulatory compliance: There must be an alignment between the governance mechanisms and the legal frameworks established by the stakeholders to ensure compliance with the regulations on the production and use of SAF, such as the performance of the RenovaCalc tool.
- Market opportunities: In conjunction with SAF producers and distributors, iteration with manufacturers and airlines favors market flexibility.
- Certification and quality assurance: Involving certifiers increases market acceptance of biofuels. In this case it would be RSB [21] which aims to create a solid scheme for the certification and traceability of biofuels. [22] [23]

To highlight one of the successes to encourage the biofuels market economically, is the system proposed in RenovaBio of the CIBOS environment, where in summary we have:

1. Issuance in the Primary Market:

The process of issuing CBIOS begins with issuance by producers or importers of biofuels. The ANP verifies invoices to determine the number of possible CBIOS. The accountant then issues CBIOS based on bilateral contracts, and the ANP provides pre-CBIOS information. The registrar assigns asset codes, updates ownership information, and registers CBIOS in the trading environment. The phase concludes with the investor's purchase offer, managed through the Brazilian Payment System.

2. Trading on Behalf of the Client:

The broker receives orders from clients specifying the amount and price range of CBIOS to be traded. The order is included in the trading platform, and the broker monitors the execution. The platform informs the registrar about the amount and price traded. The custodians process the financial agreement, transferring funds between buyer and seller through the Brazilian Payment System. Finally, the records of CBIOS holders are updated, and the registrar sends the transactions to the accountant for database updates.

3. Secondary Market:

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In the secondary market, producers, distributors, and investors participate in the negotiation. Instructions are made for buying, selling, or withdrawal requests. The custodian manages withdrawal requests, informing the registrar about operations and changes of ownership. The bookkeeper reconciles positions, while custodians or brokers oversee the registration of investors, confirmation of parties, and settlement. This secondary market completes the cycle of issuance, negotiation and withdrawal of CBIOS, providing a complete overview of how this system works in Brazil. [24] [25]

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5.6 Conclusions

Brazil has established itself as a global leader in the implementation of biofuels, particularly through policies like RenovaBio and the recent "Fuels of the Future Program." These initiatives highlight the country's commitment to reducing carbon emissions and integrating biofuels into its energy matrix. Over the years, Brazil has strengthened its biofuel production capacity, with ethanol and biodiesel being the most prominent in the transport sector. Emerging sectors, such as sustainable aviation fuel (SAF) and maritime biodiesel, are still in the developmental phases.

A key factor to consider is the distinction between first-generation and advanced biofuels. As seen in sections 6.3 and 6.4, despite Brazil's growth in biofuel production, the majority still comes from first-generation feedstocks, such as sugarcane and soybeans. Figure 5 in section 6.3 clearly illustrates that these inputs dominate biodiesel production, indicating a lack of diversification towards advanced biofuels. However, when discussing SAF production, the distinction becomes clearer, as new measures are focused on using innovative feedstocks that enhance sustainability.

Brazil's biofuel policy aligns with international standards, such as the European Union's Renewable Energy Directive (RED III), enabling the country to strengthen its position in international markets. Nevertheless, this alignment brings challenges for producers, including the need to comply with strict sustainability standards and certification processes, as well as developing a robust Decarbonization Credits (CBios) market.

The main challenges identified include the dependence on first-generation biomass, which limits the diversification into advanced biofuels. Although there are ambitious projections for SAF and maritime biodiesel production, the infrastructure for production is not fully developed, requiring significant investment in technologies and certification systems.

Finally, biofuel demand in Brazil continues to rise, driven by clear policies that set concrete targets for biodiesel blending and sustainable fuel use in sectors such as aviation and maritime transport. However, for Brazil to maintain its leadership, it will be essential to continue improving production infrastructure, ensure effective enforcement of the programs, and promote innovation in advanced biofuels and low-emission technologies.

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6 India

6.1 General overview of policy drivers

India's global policy goals in relation to biofuels are based on a multifaceted approach to addressing energy security, environmental sustainability, and economic development. The country seeks to reduce dependence on conventional fossil fuels, aligning with global efforts to mitigate climate change and achieve the Sustainable Development Goals. Support for biofuels is embedded in India's broader policy framework by promoting clean energy sources, improving energy security, and fostering economic growth. The commitment to biofuels resonates with the government's vision of a cleaner and more sustainable energy landscape, contributing to global environmental goals.

One of India's beginnings in the field of biofuels began in 2003 with the launch of the Ethanol blended Petrol (EBP) program where it is intended to sell 5% of EBP in multiple states, although from the beginning the program presented serious difficulties to be established in a correct way.

On the other hand, one of the largest sectors in India is the train sector, as it is the fourth largest in the world, it is also in the process of decarbonization, it is sought that by 2030 this sector will be within the net Zero Carbon Emissions program. The routes that are being followed to achieve this goal are the implementation of solar panels in the stations, in places close to it and the use of wind energy to supply the electricity grid, all of which is added to an update of the train fleet itself so that they can be in symbiosis with these new changes.

India recently launched its National Bioenergy Program, which is presented as a solution to increase India's energy matrix in a sustainable way, highlighting India's biomass capacity and availability in addition to the power generation capacity, and which is divided into 3 routes:

- Waste to Energy Programme.
- Biomass Programme.
- Biogas Programe.

More generally, at the last G20 summit, India launched an initiative "The Global Biofuel Alliance" which attempts to unify the recent growth of biofuels by facilitating advances in technologies, intensified the use of biofuels by creating a standard certification configuration, thus encouraging the participation of a wide spectrum of stakeholders.

In the aviation and maritime sectors, in the case of India, there is still a blank slate in terms of initiatives or projects being discussed, as there are still no commitments at the national level and few international ones. At most, we can talk about goals in the SAF because India committed to the ICAO to participate in CORSIA, where by 2027 there is a mandatory percentage of SAF use or carbon offsetting depending on the percentage of participation of the RTK (Revenue Tonne Kilometers) where India complies with this percentage, for mandatory participation the minimum is 0.5%. [1]

In the maritime area, there is the "Indo-Pacific Oceans Initiative" where India and Australia commit to work together to solve key issues such as security, ecology, resources, disaster reduction and management, as well as scientific, technological and academic collaborations.

To try to unify all types of biofuels, as well as the management and certification of these, India is pivoting through the National Policy on Biofuels created in 2018 to establish a greater use of biofuels in India by increasing production and consumption incentives. In 2022, this law was adjusted to specify sustainability criteria and new goals. Table 6-1 shows the general policies discussed above.

Table 6-1 India policy summary

Policy	Year
Ethanol Blending Petrol Programme (EBP)[27]	2014
National Policy on Biofuels[28]	2018
Indian "Green Railway" by 2030 [29]	2020
Australia-India Strategic Research Fund	2020
National Bioenergy Programme[30]	2022
Global Biofuel Alliance 2023[31]	2023

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6.2 Policy framework at country level

In India, the policy framework for biofuels is characterized by recent amendments and comprehensive initiatives aimed at promoting sustainable biofuels production and consumption.

India's National Biofuel Policy, as amended in 2022, reflects a commitment to ambitious targets, notably the accelerated deadline for achieving a 20 percent bioethanol blending rate in petrol by 2025-26. The policy's versatility is enhanced by broadening the scope of eligible feedstocks for biofuel production, fostering adaptability to emerging opportunities in the biofuel industry.

In the past, India has failed to meet its biofuel blending mandates, for example, in 2009 it proposed an ethanol blending percentage of 20% in 2017 as well as blending 20% biodiesel, reaching a minimum of 1.9% ethanol and only 0.1% biodiesel in 2017.

Beyond the National Biofuel Policy, the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative, launched in 2018, plays a new important role in the transportation industry. SATAT envisions establishing 5,000 compressed biogas (CBG) plants, producing 15 million metric tons per annum of CBG by 2023-24. This initiative promotes the adoption of CBG as an alternative fuel for transportation, aligning with India's commitment to diversify its energy sources.

The recently notified National Bioenergy Programme [7], with an established budget allocation for Phase-I until March 31, 2026, provides crucial fiscal support. This program extends subsidies and Central Financial Assistance for various biogas plants, further encouraging investment in the bioenergy sector.

The general objective is to achieve an energy transition so that by 2030 50% of electricity capacity is achieved that does not come from fossil energy resources and to achieve net zero emissions by 2070. For this reason, 3 different routes are created to achieve these objectives, the Waste to Energy program, the Biomass program, and the Biogas program.

These policy measures collectively underscore India's dedication to fostering a robust and sustainable biofuels sector. The amendments, initiatives, and financial allocations demonstrate a multifaceted approach aimed at line up biofuels production with global sustainability goals while addressing the nation's energy security needs.

To reach these goals united with sustainability objectives, the Indian government requires import licenses to import biofuels. However, the import of biofuels for fuel blending remains prohibited. The import license applies to some alcohol's, pure biodiesel, biodiesel blends over 30 percent, and petroleum oils containing up to 30 percent biodiesel.[33]

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However, today no concrete or planned measures on aviation or marine biofuels were identified in India, except for the formation of the Bio-Aviation Turbine Fuel (ATF) committee to develop a program, there are no national mandates where roadmaps for these biofuels are set. The only mandatory targets established and internationally are those of CORSIA, as India would be part of the mandatory phase from 2027, having to produce and use 1% of SAF in the sector.

As has been done with the main policy in terms of biofuels with Brazil, it is done for India in Table 6-2, where the modifications made in 2022 in the national biofuels policy have been taken into account.

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Table 6-2 Comparison between National Biofuel Policy and RED III (Own elaboration)

Aspects	National Biofuel Policy-2022 Amendments	RED III - Directive
Objectives	Economic Growth, Equity, and Energy Security	Promotion of energy from renewable sources, including targets and sustainability criteria for transport fuels, contributing to the Paris Agreement.
Renewable Raw Materials	Biomass, bio-based materials, waste, agricultural residues	Sustainable biomass, specific list of low ILUC risk feedstock for advanced biofuels production ("Annex IX-A)
Vision & Goals	Biofuel Integration, National Ethanol-Fossil Fuel Blending Targets	Increase the share of renewable energy in the total transport matrix by 29% by 2030; combined advanced biofuels and RFNBO target of 5.5% by 2030 (however, due to various multiple counting rules, lower physical quantities needed)
Biofuel Scope	Bioethanol, biodiesel, and after the 2022 update, a new definition of advanced biofuel that resembles the European directive.	Biofuels, Advanced Biofuels, Renewable Fuels of Non-Biological Origin (RFNBOs) (E-fuels)
Land Use	Use of degraded land and non-agricultural areas	Sustainable land use, avoiding areas of high biodiversity, list of low ILUC feedstock for advanced biofuels.
Minimum Support Price	Support to farmers for the cultivation of inedible oilseeds	No, the EU sets only targets, however, Member States are allowed to provide financial support to a certain degree. e
Financial Initiatives	Consideration of subsidies and aid from the national biofuels fund	Investment and R&D subsidies; but no production support.
Quality Standards	Standards for bio-diesel (IS-15607) and bio-ethanol (IS:2796:2008)	Strict standards for biofuels with stringent traceability and sustainability
Import and export of biofuels	Controlled importation, actions to avoid high costs of national biofuel production	Import permitted, if compliant with RED III sustainability criteria
Sustainable approach	Emphasis on inedible raw materials, waste and degraded land.	Set of RED III sustainability criteria including GHG savings, protecting wetlands, old grown forests, biodiverse grassland, LULUCF criteria, sustainable harvesting,
Institutional mechanisms	National Biofuel Coordination Committee (NBCC), Biofuel Steering Committee	Compliance with sustainability criteria to be verified by EC approved voluntary sustainability schemes or national sustainability schemes.

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6.3 Overview on biofuels production and use

Recently, through the national biofuels plan established in 2018, it can be seen how the country becomes the world's 3rd ethanol producer behind Brazil (USA 1st and Brazil 2nd are excluded of Figure 6-1 due to the huge gap between the others), therefore, after its success this policy was updated in 2022 to advance the blending goals established to 2025-2026. As for the percentage of biodiesel, it remains unchanged at 5% by 2030. [9]

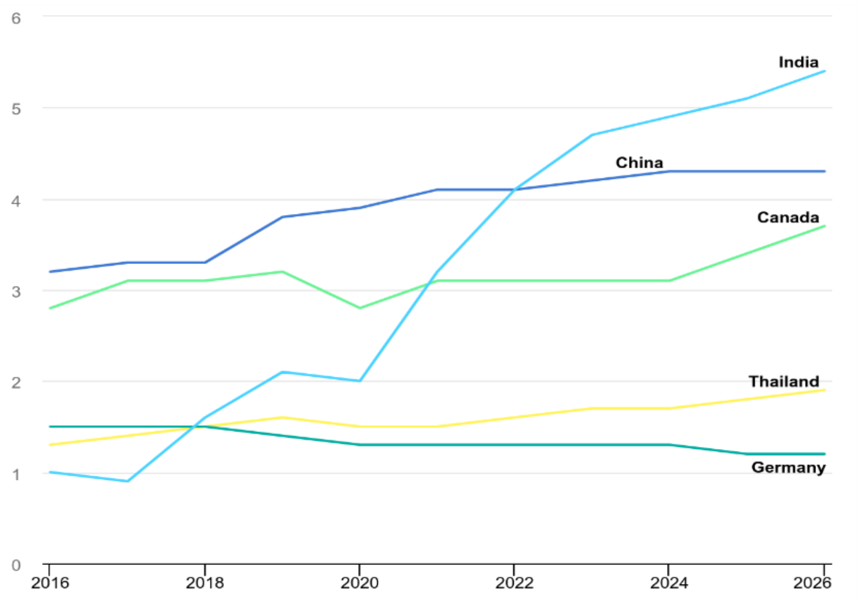

Figure 6-1: Ethanol production by country (from 3rd to 7th) and projections in Billion litres/ year

In the context of India, it is similar to that in Brazil, the most implemented biofuels and where it has been seen that they are placing the most emphasis are ethanol and biodiesel where its production is shown in Table 6-3.

Table 6-3 Main biofuel production in India.

Year	Biodiesel (1000m^3)	Bioethanol (1000m^3)
2015	100	1.100
2016	200	700
2017	200	1.500
2018	200	1.900
2019	100	1.700
2020	200	3.000
2021	200	4.000
2022	200	4.600
2023	200	5.400

Little more information can be added in this section since these numbers are mainly only being produced in terms of biofuels, in addition to the fact that the main use is for land transport. Like Brazil, there is no production of any kind when talking about the two sectors that are proposed in this project, but in the following section, can be seen what kind of measures they want to implement and how this situation changes for both sectors.

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6.4 Biofuels market demand

This ambitious target is expected to serve as a catalyst for significant demand growth in the coming years, thereby bolstering the country's biofuels industry and contributing to its overall energy sustainability goals.

However, like Brazil, India will also have to comply with the proposed sustainability and GHG reduction measures, so if we look at Figure 6-2**,** we see that the demand curve and the food supply follow an almost exponential regression and only the land transport sector is being mentioned.

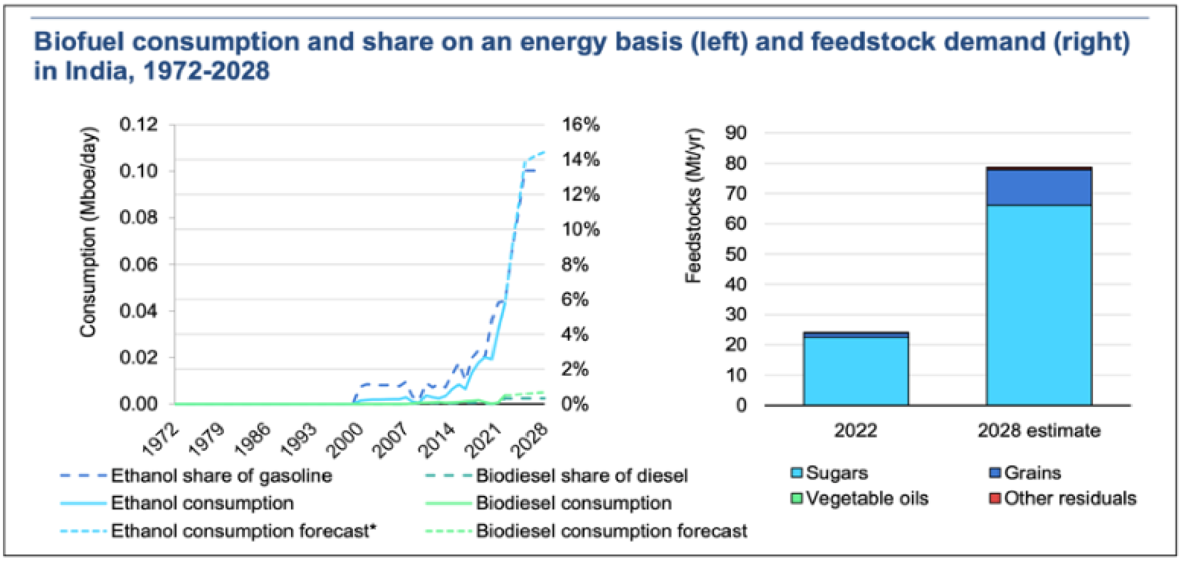

Figure 6-2 Expected biofuel consumption and feed in India.

By increasing production and market demand to 700 million liters, it is expected to increase to 1,500 million liters for 2020-2025 roadmap, this for the E20 mix. In addition, it should be noted, as mentioned before, that it has surpassed China to become the fourth largest producer of global ethanol. [10]

To focus on how the aviation sector is going to evolve, it has been used data provided by the Ministry of "Petroleum and Natural Gas" [11], which provides data on aviation kerosene production over the years by obtaining the results of Table 6-4:

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Table 6-4 Production of Aviation fuel in India

Year	Aviation Kerosene (TMT)[10]	Aviation Turbine Fuel (TMT)	Total (TMT)	Total (m^3)[11]
2018	4408	14594	19686	24.607.500
2019	4072	15479	18779	23.473.750
2020	3211	15238	11090	13.862.500
2021	2393	7092	11694	14.617.500
2022	1916	10294	14997	18.746.250
2023	948	15000	15147	18.933.712,50

Where the SAF projection transferred by the mandatory target proposed by CORSIA is 1% of the total fuel consumed. So, based on the year 2023 and considering that all the aviation kerosene produced in India is consumed domestically and also does not consider the imports that may need to meet demand, that calculation would be around **189.337,13 m^3** of SAF that India would need to meet the target.

” By 2025, if we target to blend 1% SAF blending in Jet fuel, India would require around 14 crore litre of SAF/annum. More ambitiously, if we target for 5% SAF blend, India required around 70 crore litre of SAF/ annum”, the Minister informed.”

The conversion of the 1 crore liter is equal to 10 million of liters, so by that time the Minister said that for a target of 1% SAF by 2025 India would require around 140 million of liters and for the 5% target 700 million of liters. That means that demand of the aviation fuel its around 14.000.000 m^3.

If it is compared with the table 8, as mentioned before it can be seen the differences between the data provided and the new targets would be even higher, i.e. an increase of 35.24% in the consumption of SAF.

[10] (Thousands of metric tons) This measure is used in the report, [11] To perform conversions, it is recommended to use the conversion tables provided in Appendix (XI) of the same report.
[11] To do the conversion to m3 a density of 800 kg/m3 have been used for jet fuel.

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Currently there is only one pilot plant of which there is no information on how much production capacity it has, but there is information on the technology with which it intends to produce this SAF and it will be through the ATJ route using agro-resources as food. [12]

6.5 Practical consequences for market actors

The shape of India's regulatory framework for biofuels is designed to support developers and producers through a combination of mandates, financial incentives, and a broad list of eligible feedstocks, intended to promote sustainable agricultural practices.

Measures such as the elimination of taxes for certain blending percentages for both biodiesel and ethanol have been proposed to support the country towards a renewable energy transition. [13]

As it was mentioned, the adjustment that was made to the National Biofuels Plan (2022) the advance of the goals of blending ethanol with fuel occurs from 2023 to 2025-2026, for this they expand the list of feeds available for its production. [14]

The inclusion of measures and programs that promote the acceleration of biofuels, such as within the Union Budget 2023, where suggestions to increase investment are introduced.

Through **Pradhan Mantri JI-VAN Yojana scheme [15],** biofuel projects were included in the PLI (Production Linked Incentive). In addition, the government emphasized the inclusion of biofuels within Priority Sector Lending to promote the availability of credit for biofuels projects. [16]

Finally, it is worth highlighting the special economic zones and export-oriented units, where policies promote domestic production through the "Make in India" campaign that aims to speed up and encourage this production, leading to an increase in capacity and investment in biofuel technologies.

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6.6 Conclusions

India, like Brazil, has seen remarkable growth in biofuel production, positioning itself as the world's third-largest ethanol producer. However, most of the ethanol and biodiesel produced in the country comes from first-generation feedstocks. While the National Biofuel Policy has encouraged ethanol production, with a significant increase in capacity, the primary raw materials remain sugarcane and other first-generation agricultural resources. Projections for sustainable aviation fuels (SAF) are still limited, making it premature to clearly distinguish between conventional and advanced biofuels in India.

India’s biofuel policy, particularly with the 2022 amendments, aims to accelerate ethanol blending targets and diversify the feedstocks available for biofuel production. This highlights the country’s commitment to expanding its biofuel industry, though significant steps are still needed to fully integrate advanced biofuels into the national energy mix.

Like Brazil, India's biofuel production focuses predominantly on land transport, with minimal development in the aviation and maritime sectors. The implementation of SAF production remains in the early stages, and the country is yet to establish clear roadmaps for advanced biofuels in these industries.

As India increases its production and demand for biofuels, it will be essential to diversify its biomass sources and enhance sustainability efforts. The successful integration of advanced biofuel technologies will play a crucial role in helping India meet its renewable energy targets and contribute to global efforts to reduce carbon emissions.

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7 Initiatives

In addition to the focus on a policy overview, this chapter provides information on operational and planned liquid transport biofuels production initiatives. Focus lies in the aviation and maritime sector. Within this report, initiatives mean market players that develop demonstration plants which have an impact on the market demand. Due to the current strong market dynamics, not all of the relevant initiatives can be mentioned in this report, but some of them will be mentioned as examples.

In addition to market initiatives, the BioTheRoS project aims to list the different research projects on advanced biofuels for shipping and aviation. This list of projects and research groups will be developed in Task 7.1, which will be published in a separate deliverable.

7.1 Overview of technology pathways

This chapter provides a brief overview on technology pathways, which can produce liquid biofuels for road transport, aviation, and maritime. The technology pathways are briefly described in Table 7-1.

Within Europe, four technology pathways have reached market maturity and provide relevant volumes, namely FAME, HVO, conventional ethanol and biomethane via anaerobic digestion. In 2023, production volumes and capacities amounted to: FAME (9.9 million t/a production and 12 million t/a capacity), HVO (5.1 million t/a production and 5.1 million t/a capacity), ethanol (5.1 million t/a production and 5.8 million t/a capacity), and biomethane (3.8 billion m^3/a production). The production volumes of advanced ethanol and pyrolysis amounted to 200,000 t/a and 100,000 t/a respectively [1]. The volumes of FAME, HVO and ethanol can be mainly attributed to the road sector. However, these have increasing relevance for the aviation and maritime sector. Biomethane has several applications and only a small fraction is used as transport fuel.

The other listed technology pathways are not yet producing at industrial-scale. Sustainable aviation fuels (SAF) can be produced e.g. via HVO, gasification or ATJ. Potential maritime fuels include HVO, ethanol, methanol, hydrogen, biomethane (liquefied) and fuels produced via pyrolysis. Ammonia is also discussed as potential maritime fuel. However, there are concerns due to its toxicity, which would add complexity to ship designs and require further research.

Table 7-1: Overview on technology pathways (Sources: [2] ETIP Bioenergy, [3] EASA, [4] EMSA)

Technology pathway	TRL	Feedstock	Conversion	Product/Application	Source

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Biomethane via anaerobic digestion	9	Biowaste, manure, agricultural residues	Anaerobic digestion	Biogas for heat and power or upgrade to biomethane	[2]
HVO/HEFA (Hydroprocessed vegetable oil/esters and fatty acids)	9	Vegetable oil, waste oils and fats	Hydroprocessing	Drop-in biofuel HVO/HEFA for road transport or aviation	[2]
FAME (Fatty acid methyl ester)	9	Vegetable oil, waste oils and fats	Transesterification	Biodiesel for road transport	[2]
Conventional ethanol	9	Corn, wheat	Fermentation	Bioethanol for road transport or ATJ	[2]
Advanced/Cellulosic ethanol	5-8	Lignocellulosic residues, industrial waste	Fermentation	Advanced bioethanol for road transport or ATJ	[2]
Alcohol-to-jet (ATJ)	7-8	Ethanol from agricultural or forestry residues, isobutanol	Alcohol dehydration, olefin oligomerization, hydrogenation	SAF	[3]
Gasification	5-8	Lignocellulosic biomass, energy crops, forestry and agricultural residues	Gasification to syngas, synthesis (methanation, Fischer-Tropsch, etc.)	Methanol, SNG, DME, FT-Diesel, SAF	[2]
Pyrolysis	5-8	Lignocellulosic biomass, municipal solid waste, and agricultural waste	Pyrolysis, upgrading	Pyrolysis oil for co-processing, upgrading and marine fuels	[2]
HTL (Hydrothermal liquefaction)	4-5	Food processing waste, manure, municipal sludge	Hydrothermal liquefaction, upgrading	Bio-crude, upgrade to transport biofuels	[2]
Biogenic Ammonia	7-8	Woody biomass	Thermal gasification	Ammonia as marine biofuel	[4]

7.2 SAF production initiatives

Sustainable Aviation Fuels (SAF) are discussed as an important way to reduce GHG emissions of the aviation sector, which is responsible for about 2% of global energy-related CO_2 emissions [5] and 14.4% of EU transport emissions [6]. The aviation sector is forecast to grow continuously by around 3.4% per year, with demand for air travel set to double by 2040 [7]. Additionally, in October 2022 member states of the International Civil Aviation Organization (ICAO) agreed to a long-term aspirational goal (LTAG) of net-zero CO_2 emissions from aviation by 2050 [8]. The estimated volume of SAF needed to achieve this target is above 400 billion liters. The European ReFuelEU Aviation Initiative [9] includes a blending mandate of 70% SAF by 2050. The impact assessment of the Initiative foresees the need for around 105

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SAF production facilities in Europe by 2050 [10] (at that time the targeted blending mandate was 63% by 2050).

Today, there are only a limited number of SAF production facilities operational, as can be seen in Figure 7-1. Some more are planned or under construction. There are announcements for SAF production initiatives nearly on a weekly basis. IEA Bioenergy Task 39, as well as ICAO, tracks operational and announced facilities, which produce SAF or could produce SAF in future [11,12]. Main challenges of SAF market uptake (and an explanation of the gap between projected demand and operational initiatives) include the high production costs of SAF compared to conventional fuels, limited availability of sustainable feedstock (biomass, electricity), and a lack of clear international regulations and alignment between them [13].

Figure 7-1: SAF production facilities in Europe (Source: IEA Bioenergy Task 39)

Another option to track SAF development are offtake agreements. ICAO lists SAF offtake agreements [14], which gives a first impression on the dynamic market development. As can be seen in Figure 7-2, the volume of SAF offtake agreements sharply increased in 2021, peaked in 2022 with more than 20 million liters, and is now decreasing. The total number of offtake agreements since 2013 amount to 124, between 47 (potential) fuel producers and 65 (potential) fuel purchasers. It should be noted that offtake agreements only provide an indication. It does not mean that all of the announced production facilities will be operational and it also doesn´t give information about the planned timeframe. Therefore, the actual SAF volumes, which will be available in the next years is unclear.

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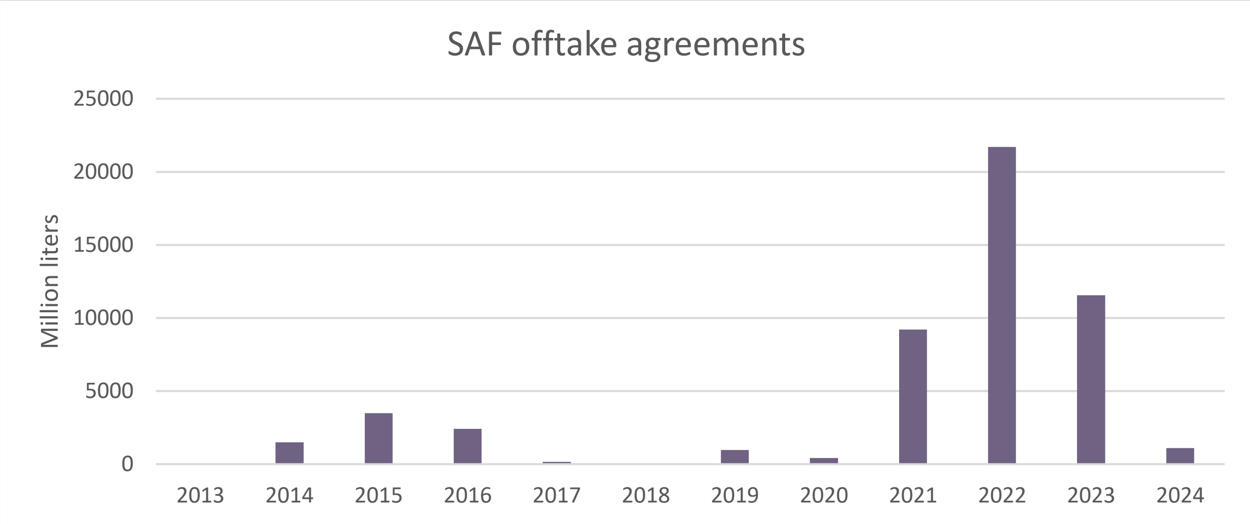

Figure 7-2: SAF offtake agreements (Source: Based on ICAO)

The top ten fuel producers with the highest volumes of SAF offtake agreements as listed by ICAO are:

1. Gevo (9,550 million liters)
2. Fulcrum (6,719 million liters)
3. Alder Renewables (5,678 million liters)
4. Cemvita (3,785 million liters)
5. USA BioEnergy (3,255 million liters)
6. Shell (2,793 million liters)
7. Neste (2,456 million liters)
8. DG Fuels (2,301 million liters)
9. Raven SR (1,562 million liters)
10. OMV (1,437 million liters)

IEA Bioenergy Task 39 published a report showing the progress in the commercialization of SAF [15]. This report lists announced initiatives of potential SAF producers, based on information of Argus Media. There are 56 initiatives for HEFA-SPK (10 of these planned in Europe), 18 for Gasification-FT (9 of these planned in Europe), 20 for Alcohol-to-Jet (6 of these planned in Europe), 26 for Power-to-liquid (20 of these planned in Europe, 1 operational in Europe) and 13 for co-processing (2 of these planned in Europe, 10 operational in Europe). Table 7-2 includes announced initiatives of the top ten fuel producers according to offtake agreements.

Table 7-2: List of initiatives of top ten fuel producers according to SAF offtake agreements [15]

Company	Technology pathway	Location	Capacity [million liters/y]	Status
Gevo	Alcohol-to-Jet	South Dakota, USA	197.5	Planned
Gevo	Alcohol-to-Jet	Silsbee, Texas	0.4	Planned

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Fulcrum	Gasification-FT	Gary, Indiana	118.8	Planned
Fulcrum	Gasification-FT	Reno, Nevada	41.3	Operational
Fulcrum (+ Essar Oil)	Gasification-FT	Stanlow, UK	104.6	Planned
USA BioEnergy	Gasification-FT	Bon Weir, Texas, USA	-	Planned
Shell	Power-to-liquid	Louisiana, USA	542.5	Planned
Shell	Power-to-liquid	Wesseling, Germany	125.0	Planned
Shell	HVO/HEFA	Rotterdam, Netherlands	545.0	Planned
Neste	HVO/HEFA	Singapore	1250.0	Planned
Neste	HVO/HEFA	Rotterdam, Netherlands	625.0	Planned
DG Fuels	Gasification-FT	Louisiana, USA	628.8	Planned
OMV	Co-processing	Schwechat, Austria	-	Operational
OMV	Co-processing	Petrobrazi, Romania	-	Operational

Additionally, there are numerous other initiatives announced. Planned HVO plants with high capacities include SGP Bioenergy in South America (4681.3 million liters/y), Fidelis New Energy in Louisiana, USA (2215 million liters/y) or Oriental Energy in Guangdong, China (1250 million liters/y). As for ATJ, there is an initiative planned by Lanazjet/Marquis, with a capacity of 431.1 million liters/y, located in Illinois, USA. Another example of an ATJ initiative, but planned to be located in Europe, is the project Speedbird. British Airways, LanzaJet and Nova Pangaea plan to produce 102 million liters/a of SAF for commercial use in UK, utilizing agricultural and wood waste. The project was initially launched in 2021 and it is expected to produce SAF by 2026[12].

Table 7-3 lists initiatives in Europe, via the Gasification-FT pathway. Most capacities are planned in UK. The initiative with the greatest capacity among them is planned from Lighthouse Green Fuel Ltd. In this facility over a million tons of non-recyclable waste and waste biomass will be processed to SAF for the use in international and domestic flights[13]. Fulcrum and Essar oil are planning a SAF production facility based on non-recyclable household waste for airlines operating at UK airports. Enerkem and Shell are planning to repurpose a planned waste-to-chemical plant at the port of Rotterdam to a waste-to-jet plant, processing hard-to-recycle waste to SAF[14].

Table 7-3: List of SAF initiatives in Europe via Gasification-FT [15]

Company	Location	Capacity [million liters/y]	Status
Fulcrum (+ Essar Oil)	Stanlow, UK	104.6	Planned
Velocys	Immingham, UK	62.5	Planned
Greenergy	Thames Enterprise Park, UK	-	Planned
Lighthouse Green Fuel	Billingham, Teesside, UK	108.3	Planned

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Quantafuel	Norway	8.6	Planned
TotalEnergies (BioTFuel)	France	-	Planned
Repsol	Bilbao, Spain	2.6	Planned
Enerkem	Rotterdam, Netherlands	75.0	Planned
KLM	Vaxjo, Sweden	20.0	Planned

Besides the Gasification-FT initiatives dedicated for SAF production, the database on facilities for the production of advanced liquid and gaseous biofuels for transport of IEA Bioenergy Task 39 [11] lists gasification initiatives producing FT-liquids (e.g. Cutec in Germany, Tubitak in Turkey, Biojet AS in Norway) or methanol (e.g. Enerkem in Spain or Gidara Energy in the Netherlands).

7.3 Maritime biofuel initiatives

Utilizing biofuels in shipping is crucial for reducing greenhouse gas emissions as it offers a sustainable alternative to traditional fossil fuels, helping to mitigate environmental impact and combat climate change. Given that shipping plays a significant role in the global economy, facilitating the transportation of the majority of world trade, it accounts for approximately 2-3% of global greenhouse gas emissions and stands as the largest source of anthropogenic sulphur emissions. Due to its nature as a long-distance transport sector, electrification poses challenges and is not the most viable option for reducing greenhouse gas emissions. However, drop-in biofuels and advanced biofuels present considerable potential for decarbonizing this mode of transportation. The International Maritime Organization (IMO) has set ambitious targets aimed at mitigating the environmental impact of shipping, including a 70% reduction in greenhouse gas emissions by 2040 compared to 2008 levels [16].

Industry, international networks and research groups have identified applicable fuels for the shipping industry with different levels of Technology Readiness [17]. Those fuels include FAME (biodiesel), pyrolysis oil (and upgraded pyrolysis oil), methanol, ammonia, liquefied and compressed biogas, renewable natural gas, hydrotreated vegetable oil, ethanol, hydrogen and electricity. The most promising biofuel categories according to stakeholders from a questionnaire of IEA Bioenergy Task 39 are Pyrolysis oil/Hydrothermal liquefaction, alcohol/lignin and RNG [18].

Currently, the production and uptake of marine biofuels remain relatively limited. Regarding initiatives, it is relatively difficult to give a comprehensive list, because most of the advanced biofuel facilities are not dedicated to the marine sector. However, there are several initiatives, which are producing advanced biofuels suitable for shipping or with plans for additional facilities either in progress or in the developmental stages. Organizations such as IEA Bioenergy Task 39, IMO or DNV monitor both operational and announced facilities capable of producing marine biofuels. Figure 7-3 shows European

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facilities producing bio-oil, clean syngas, biogenic diesel, ethanol, hydrogen, methanol, pyrolysis oil, renewable diesel (HVO) and SNG [11]. The Alternative Fuels Insight Database from DNV [19] shows fuel production facilities in Europe producing methanol, ammonia, hydrogen and biofuels (see Figure 7-4). Both databases show facilities which are capable of producing fuels for the maritime sector, but those are not dedicated facilities.

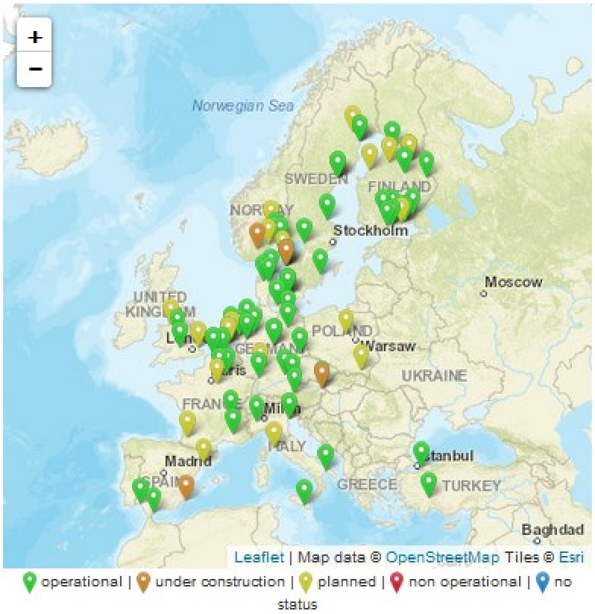

Figure 7-3: Advanced biofuel production facilities suitable for shipping (Source: IEA Bioenergy Task 39)

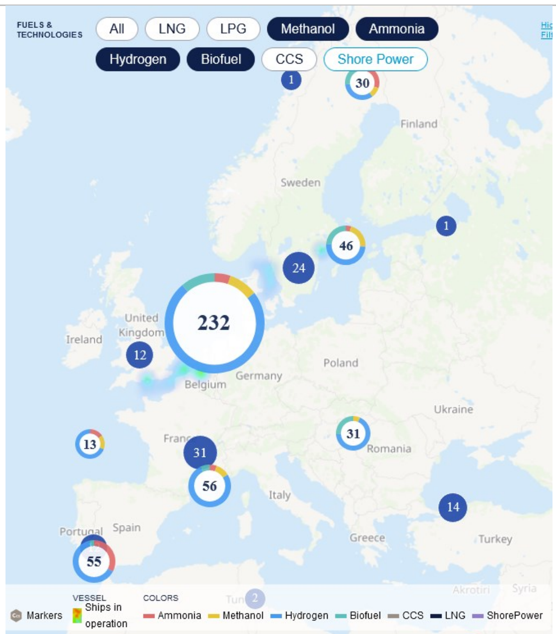

Figure 7-4 European alternative Fuel production facilities (Source: DNV AFI)

Key players in the production of marine biofuels are the following companies: Cargill, Chevron, TotalEnergies, BP and Exxon Mobil, as well as UPM, GoodFuels and Neste Oil [20].

In 2021 IEA Bioenergy Task 39 published a report showing the progress towards biofuels for marine shipping [18]. Within this report currently operating commercial facilities of advanced biofuels and announced facilities are listed, where the operating facilities focus primarily on HVO production from oil crops, pyrolysis oil from forest residues, and cellulosic ethanol from agricultural residues. Currently, these advanced biofuels are produced for all transport sectors, and it is most likely that they actually represent a much lower share of shipping fuels.

Table 7-4 includes operational and announced initiatives of advanced biofuel production in Europe, which are capable of being used for the maritime sector. These facilities often offer flexibility in their final product, allowing for various formulations or accommodating different product sectors; products for the aviation, maritime and road sector are produced in the same facility.

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Table 7-4: List of European facilities for the production of advanced biofuels suitable for the maritime sector [11]

Company	Technology pathway	Location	Product	Capacity [tons/y]	Status
Enerkem, SA (Agbar), Repsol	Gasification	El Morell, Spain	Methanol	265,000	planned
Gidara Energy	Gasification	Amsterdam, Netherlands	Methanol	87,500	planned
BioMCN	Gasification	Farmsum, Netherlands	Methanol	65,000	operational
Cepsa	Hydrotreatment	Huelva, Spain	HVO	500,000	planned
Eni	Hydrotreatment	Gela, Italy	HVO	750,000	operational
Repsol	Hydrotreatment	Cartagena, Spain	HVO	250,000	operational
Total	Hydrotreatment	La Mede, France	HVO	500,000	operational
UPM Biofuels	Hydrotreatment	Lapeenranta, Finland	HVO	130,000	operational
Neste	Co-processing	Porvoo, Finland	HVO	380,000	operational
Green Nordic Fuel	Fast pyrolysis	Lieksa, Finland	Pyrolysis oil	24,000	operational
Pyrocell (JV of Setra and Preem)	Fast pyrolysis	Gävle, Sweden	Pyrolysis oil	24,000	operational

As stated earlier those facilities are not dedicated solely to maritime fuels, but the produced advanced biofuels are the basis for maritime fuels. Some refineries take the approach of producing partly for the aviation sector and partly for maritime or road applications.

7.4 Other relevant initiatives

In Europe other relevant initiatives for the production of advanced biofuels exist which do not fall in the categories of SAF or maritime fuels. The Project BIKE (Biofuels production at low-ILUC risk for European sustainable bioeconomy) provided an overview of biofuel production facilities in Europe in 2021 [21], using, among other sources, maps published by JRC [22] and the Biobased Industry Consortium. According to the project report, there were 27 HVO plants (Sweden (8), Finland (7), Spain (3), Denmark, Italy and Netherlands (2), UK, Ireland, Czech Republic (1)), and 28 cellulosic ethanol plants (Denmark (7), Finland (5), Norway (3), Sweden, Slovakia (2) Spain, France, Germany, Austria, Italy, Poland, Croatia, Romania and Bulgaria (1)) operational in Europe in 2021.

IEA Bioenergy Task 39 tracks in its database facilities for the production of advanced liquid and gaseous biofuels for transport. The European initiatives with the highest capacities among those are listed in Table 7-5. Plants that are dedicated to produce aviation or marine fuels are listed in the previous

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chapters. It has to be noted that fuels can be used for more than one transport mode and most plants are producing more than one different fuel. Therefore, there is no strict categorization.

Table 7-5: European initiatives for liquid biofuels [11]

Company	Technology pathway	Location	Capacity [tons/y]	TRL	Main output	Status
Preem	Hydrotreatment	Lysekil, Sweden	920,000	9	Diesel with biogenic content	Planned
UPM Biofuels	Hydrotreatment	Kotka, Finland	500,000	8	HVO/HEFA	Planned
Eni	Hydrotreatment	Livorno, Italy	500,000	9	HVO/HEFA	Planned
SCA	Hydrotreatment	Östrand, Sweden	156,000	6-7	HVO/HEFA	Planned
Biozin	Fast Pyrolysis	Amli, Norway	100,000	8	Pyrolysis oil	Under construction
Kanteleen Voima	Fermentation	Haapavesi, Finland	65,000	6-7	Ethanol	Planned
Liquid Wind / Orsted	E-Fuels Biomass Hybrids	Ornskoldsvik, Sweden	50,000	8	Methanol	Planned
St1	Fermentation	Ringerike, Norway	40,000	8	Ethanol	Planned
St1	Fermentation	Kajaani, Finland	40,000	8	Ethanol	Planned
St1	Fermentation	Pietarsaari, Finland	40,000	8	Ethanol	Planned
ORLEN Poludnie	Fermentation	Jedlicze, Poland	25,000	9	Ethanol	Planned
RYAM	Fermentation	Tartas, France	17,000	9	Ethanol	Planned
Nordic Electrofuel AS	E-Fuels Biomass Hybrids	Porsgrunn, Norway	8,000	8	FT liquids	Planned

In addition to biofuels, several other alternative fuels are being explored to decarbonize the shipping sector. Among these alternatives are E-fuels, such as Power-to-Liquid (PtL) fuels, which are produced by converting renewable electricity into synthetic liquid fuels. E-Methanol and e-Ammonia are also gaining attention as promising options. These alternative fuels offer potential pathways to reduce greenhouse gas emissions in the transport sector including aviation, maritime and road transport.

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