Advanced Sustainable BIOfuels for Aviation

Deliverable D5.2:

Report on market dynamics

Consortium:

Acronym	Legal entity	Role
RE-CORD	CONSORZIO PER LA RICERCA E LA DIMOSTRAZIONE SULLE ENERGIE RINNOVABILI	CO
TRC	TOTAL RAFFINAGE CHIMIE SA	BEN
TRF	TOTAL RAFFINAGE FRANCE	BEN
SKYNRG	SKYENERGY BV	BEN
CENER	FUNDACION CENER-CIEMAT	BEN
ETA	ETA – Energia, Trasporti, Agricoltura Srl	BEN
CCE	CAMELINA COMPANY ESPANA S.L.	BEN
JRC	JOINT RESEARCH CENTRE – EUROPEAN COMMISSION	BEN

CO…Coordinator, BEN…Beneficiary

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 789562.

General Information

Call identifier:	H2020-LCE-2017-RES-IA
GA Number:	789562
Topic:	LCE-20-2016-2017
Start date of project:	01/05/2018
Duration:	4 years (30/04/2022)
Work Package:	WP5 – Market Scaling Strategy
Type:	Deliverable
Number:	D5.2
Title:	Report on market dynamics
Due Date:	31/10/2019 (Month 18)
Submission date:	31/10/2019
Reference Period:	01/05/2018 – 31/10/2019
Prepared by:	SkyNRG (Lead), CENER, RE-CORD, TOTAL
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Dissemination Level:	Public

INTERNAL MONITORING & REVISION TABLE					
REV.	**DATE**	**DESCRIPTION**	**PAGES**	**CHECKED**	**APPROVED**
1	**18-10-2019**	**Draft**	**30**	**All**	**SKY**
2	**28-10-2019**	**Final**	**29**	**All**	**SKY**

Document Type		
PRO	Technical/economic progress report (internal work package reports indicating work status)	
DEL	Technical reports identified as deliverables in the Description of Work	**X**
MoM	Minutes of Meeting	
MAN	Procedures and user manuals	
WOR	Working document, issued as preparatory documents to a Technical report	
INF	Information and Notes	

Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	
CON	Confidential, only for members of the Consortium	

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1 Abbreviations

ASTM – American Society for Testing and Materials
CORSIA – Carbon Offsetting and Reduction Scheme for International Aviation
EC – European Commission
EU – European Union
EU28 – Member States of the European Union
FQD – Fuels Quality Directive
FT – Fischer-Tropsch
GHG – Greenhouse Gas
HBE – 'Hernieuwbare Brandstofeenheid', Renewable Energy Unit
HEFA – Hydro-processed Esters and Fatty Acids
HVO - Hydrogenated Vegetable Oil
IATA - International Air Transport Association
LCA – Life Cycle Assessment
OEM's – Original Equipment Manufacturers
PoS – Proof of Sustainability
RED – Renewable Energy Directive
RSB – Roundtable of Sustainable Biomaterials
SAF – Sustainable Aviation Fuel
t – metric ton, equal to 1,000 kg
    kt – 1,000 t
    Mt – 1,000,000 t
UCO – Used Cooking Oil
UN–ICAO – United Nations International Civil Aviation Organization

2 Summary

The goal of this report is to identify and discuss the most important market dynamics around Sustainable Aviation Fuels, specifically looking at the HEFA production pathway. Although the market of SAF is still very much a nascent market, we identified an increased interest from the aviation industry to curve its ever-increasing CO_2 emissions caused by the ongoing growth of the industry. Market based policy measures, like CORSIA, are a good start but will not enable the uptake of SAF. This is mainly due to the low price of CO_2 offsets which can currently be used to cover the growth of aviation under CORSIA. The price of SAF is considerably higher than these CO_2 offsets, which makes specific and dedicated policy vital to structurally stimulate demand. The transposition of the RED II legislation is an important first step to allow SAF to become competitive with other transport modes.

The HEFA technology can produce a slate of hydrocarbons. This allows the technology providers and owners of facilities to choose whether they produce primarily diesel or jet fuel. The extend to which a facility can produce more jet or diesel depends on the specific technology and chosen set-up of the refinery. In general, most HEFA, or HVO-facilities, focus their production on renewable diesel as the yield towards diesel is generally higher and specific policy to push renewable fuels in the road transport sector already exists. To break this impasse and to enable the construction of additional SAF capacity, dedicated policy is necessary.

At the same time, the HEFA pathway specifically is limited by the availability of sustainable feedstocks. Aviation is known for having high sustainability and quality standards. One of the risks of scaling this industry too rapidly is that lower sustainability standards are accepted in order to get competitive with other industries. This can cause serious backlash which would be harmful for this nascent industry. It is therefore important to keep developing new technologies, and in the case of HEFA facilities, diversification of the feedstock base is necessary. Both on the vegetable oil side (low-ILUC vegetable oils) as well as sustainable waste and residues.

3 Introduction

This market dynamics report will focus on the elements influencing the market uptake of Sustainable Aviation Fuels, especially focusing on the market elements influencing the Hydro-processed Esters Fatty Acids (HEFA) process pathway. Although HEFA is the focus of Bio4A and of this report, we will also cover the (conventional) jet fuel market and other Sustainable Aviation Fuel (SAF) production pathways as these are to some extend competing products.

The market for SAF is still a voluntary market, meaning there are currently no enforced mandates in place. Although there are policy mechanisms in place in (parts of) the EU and the USA that incentivize the use of SAF, these incentives have thus far not resulted in large scale SAF usage. As price premiums for SAF remains the biggest hurdle, uptake has been limited to relatively small amounts and the industry is still very much a nascent industry. To provide background in these dynamics this document starts with the assessment of current market status and uptake of (sustainable) aviation fuel. Given the importance of policy frameworks, we first discuss policy relevant policies and corresponding sustainability requirements before ending with SAF pricing.

Aside from economics, one of the limiting factors for the HEFA technology is the availability of sustainable feedstocks. The type of feedstock determines not only the price but also the Green House Gas (GHG) saving potential of the SAF. As the sustainability of SAF is heavily scrutinized and part of the public debate, the sustainability performance of the fuel will determine the likelihood of success in the market. Therefore, we will assess the EU and non-EU sustainability frameworks and trends in the second section of this report.

The HEFA process is able to convert any triglyceride to saturated hydrocarbons. Besides hydrocarbons in the jet range (approx. C8 – C16) lighter fractions like LPG and Naphtha will also be produced. The jet range is very close to the Diesel range (approx. C12 – C20). This leads to the situation where HEFA producers can to a certain extend steer their process to either jet fuel or diesel. The interaction between the adjacent markets of SAF will be discussed throughout the document and specifically be pointed out in the concluding remarks of this report.

4 Market Dynamics

4.1 Current state of SAF market

4.1.1 Emissions in the Aviation Industry

The aviation industry plays a major role in everyday life in Europe. The development of the aviation industry has brought prosperity in the form of economic growth and connectivity with the entire globe. However, this development of aviation also has had its impact on the environment. A recently published report regarding the European Aviation industry[1], shows that the number of flights increased by 8% between 2014 and 2017, and further growth of 42% from 2017 to 2040 is expected. The aviation industry has shown a yearly 1% efficiency increase due to the use of new aircraft and more efficient operation. However, this has not prevented the flight related CO_2 emissions to increase with 10% to 163 t in 2017. This comes down to the aviation sector being responsible for 3.6% of total EU28 greenhouse gas emissions.

On a global scale, growth is likely to be even more significant due to the impact of upcoming markets. According to UN-ICAO[2], the fuel consumption of international aviation during 2010 accounted for 142 million t of Jet fuel per year. Jet fuel demand is estimated to grow to approximately 860 million t per year by 2050, if only air fleet renewal and air travel demand management are adopted as CO_2 mitigation measure. This fuel volume corresponds to 71% of the expected global (i.e. International and Domestic) demand: today, global jet fuel demand accounts for 300 million t per year with approximately 200 million t per year of which used in International Aviation. Even if very substantial consumption-reduction improvement measures are implemented by ad-hoc designed policies, the jet fuel demand increase might be limited to 570 million t per year at 2050 for International Aviation only. Still more than 4 times the demand observed in 2010.

Aviation's CO_2 emissions can for 99% be related to the consumption and use of jet fuel. As the consumption-reduction and improved efficiency measure are insufficient and radically new aircraft are not yet commercially available, it is clear that a sustainable fuel alternative needs to be developed. SAF could theoretically substitute 100% of Jet-A[3]. To produce 860 million t of SAF in 2050, we would require building approximately 60 new biorefineries (500,000 t each) every year from 2020 to 2050. With a construction size and pace not even close to these numbers, the challenge becomes clear. Even a less ambitious scenario to replace 10% Jet-A1, or 86 million t per year, would still require major investments in the sector as current operational HEFA facilities focusing on continues jet fuel production only reach approximately 5,000 - 15,000 t per year in the world[4].

4.1.2 Sustainability Targets in Aviation

In 2010, the IATA member airlines have adopted a set of ambitious targets[5] to address this rise in emissions and reduce the industry's footprint. Leading to three clear targets (Figure 1).

- Improve fuel efficiency by 1.5% till 2020
- From 2020 onwards grow carbon neutrally
- By 2050, net carbon emissions should be halved compared to 2005 levels

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[1] European Aviation Environmental Report (EAER, 2019)

[2] UN-ICAO. Trends and scenario on alternative fuels – Working Paper. Conference on Aviation and Alternative Fuels, Mexico City, 11-13 October 2017, Mexico. Available at https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.006.4.en.pdf

[3] Currently not possible due to ASTM regulation, in future with newly accepted pathways this could be a possibility.

[4] World Energy refinery, Los Angeles.

[5] https://www.iata.org/policy/environment/Pages/climate-change.aspx

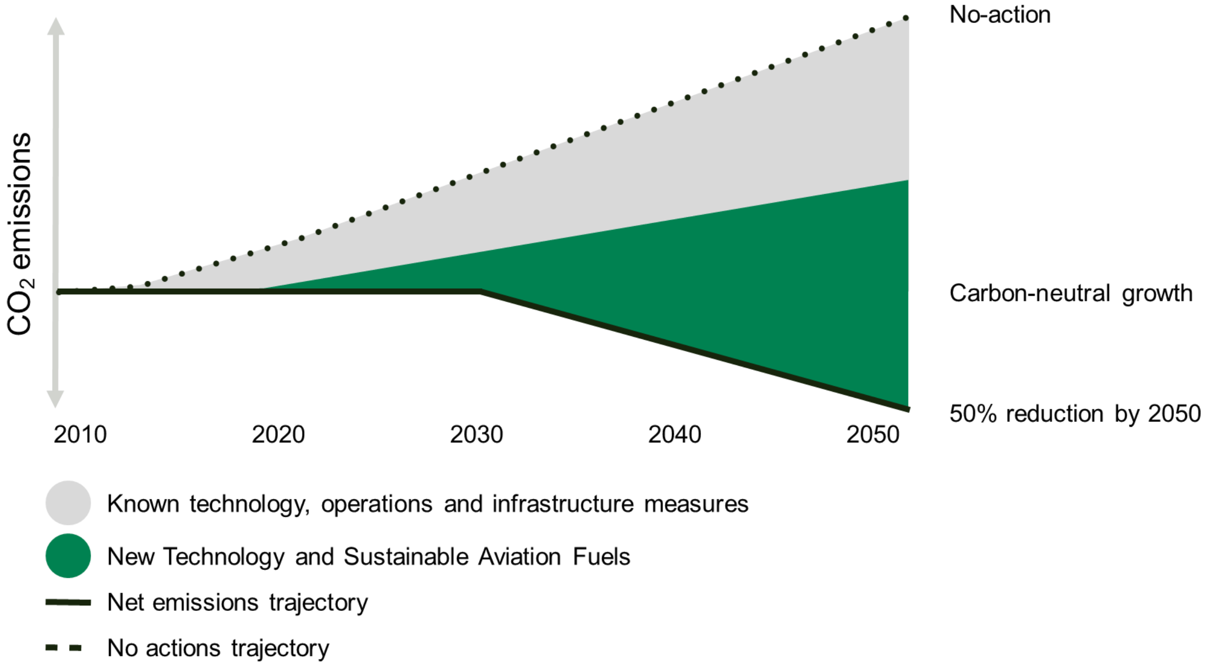

Figure 1. Aviation industry CO_2 emission reduction ambition

The first goal of 1.5% improvement has been reached over the past years, with investments in new aircraft and improving operational efficiency, due to the efforts of amongst others the Single European Sky project[6]. As can be seen in Figure 1 and discussed in the previous chapter, efficiency improvements will not be enough to cope with the increased demand nor is it a viable measure to reduce CO_2 emissions towards the 2050 target. This, combined with the fact that planes are not able to switch to alternative energy sources like hydrogen or electricity in the foreseeable future, sustainable aviation fuels (SAF) made from renewable feedstock are extremely important to significantly reduce the industry's carbon footprint.

Concluding, decarbonizing Aviation is a challenging but unavoidable action to fight Climate Change, heavily dependent on the introduction of cleaner aviation fuels (SAF), as also remarked in several occasions by the European Commission[7]. Shifting to SAF, such as advanced biofuels, recycled carbon fuels, and carbon-free e-fuels, is an urgent need, preferably combined with hybridization and other improvements in aircraft technologies.

4.1.3 SAF technology pathways and HEFA production capacity

Although Bio4A focuses on the HEFA pathway, it is important to understand the technological field and production pathways in which the HEFA process needs to compete. This will be discussed in more detail in the following section.

4.1.3.1 Technology development

The development of new conversion technology pathways to produce any type of fuel from biomass is known to be long in time and complex in content: new processes and technical solutions, in fact, require adequate time to become full industrial products. Among many possible exemplary cases, the technological development of pyrolysis technology in the Netherlands at the University of Twente, and then BTG, is worth to be mentioned since more than 30 years

[6] https://ec.europa.eu/transport/modes/air/ses_en

[7] European Commission. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK. A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.

passed from the initial lab work at Twente University to the industrial scale at BTG-BTL[8]. Similar pathways are observed for almost all innovative industrial technologies that developed at scale in the last decade, such as gasification-FT, waste-to-fuels, gas fermentation, etc.

The curve describing the route from lab, to pilot, demo and then "First Of A Kind (FOAK)" plants in the Advanced Biofuels and Recycled Carbon Fuels sectors has been well depicted by Maniatis[9]: the development of industrial scale demonstration plants for biofuels requires significant investments, most often measurable in the order of several tens or more than hundreds of million €, and adequate financial instruments. Therefore, industrial initiatives are difficult to co-finance as scale increases (from pilot to demo), since the risks associated to the most innovative solutions are substantial; plants are often operated in a non-commercial way, i.e. not yet generating profits, still containing different levels of technical risks, and projects are therefore not easily bankable. For these reasons, the curve (Figure 2) describing the innovation pathways is called the Mountain of Death, as many initiatives fail at this stage, mostly for financial reasons, rather than at R&D and lower TRL level.

With regards to aviation, the possible pathways to develop new biomass-based aviation biofuel chains are numerous and positioned at different stages of the above reported Mountain of Death curve. A more detailed description of the relevant SAF conversion pathways is provided in the next section.

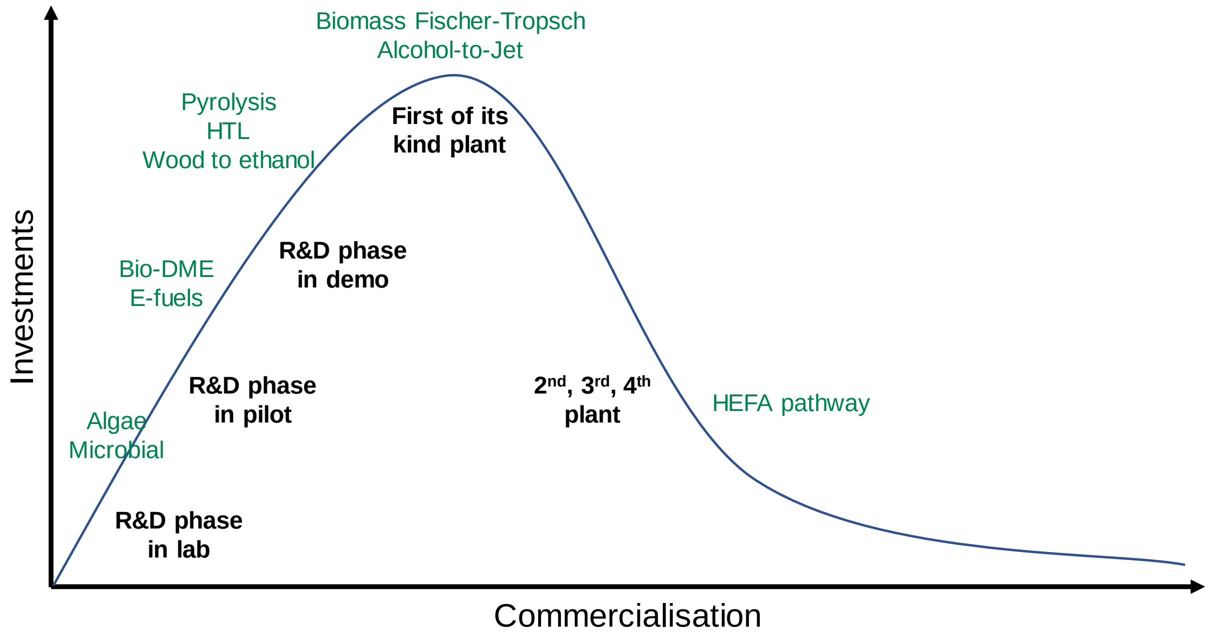

Figure 2. The "Mountain of Death" for innovative biomass technologies[9]

4.1.3.2 SAF conversion pathways

From a technical point of view, it is possible to convert any type of organic matter into SAF (setting aside the economics). Next to HEFA, we can distinguish three main conversion pathways that have the potential to produce a drop-in alternative for fossil kerosene:

- Hydo-processed Esters Fatty Acids (HEFA)
- Fischer-Tropsch (FT)
- Sugar Conversion (e.g. Alcohol-to-Jet, Synthesized Iso-paraffins)

[8] Balan V, Chiaramonti D, Kumar S. Review of US and EU initiatives toward development, demonstration, and commercialization of lignocellulosic biofuels. Biofuels, Bioprod. Bioref. (2013). DOI: 10.1002/bbb.1436

[9] The Alternative and Renewable Transport (ART) Fuel Forum. www.artfuelsforum.eu

- Direct Liquefaction (e.g., pyrolysis, hydrothermal liquefaction)

For each of these pathways there can be specific production set-ups. It is important to note that the use and quality assurance of SAF in commercial aviation is fundamentally different from the use of biodiesel or other renewable fuels in road transport. The production and use of SAF is limited to those technological pathways that have been certified by ASTM. The main aviation fuel certification body that currently certifies both fossil (under D1655) as well as sustainable aviation fuels (D7566)[10]. Once a new production pathway is seeking ASTM certification it needs to get through various so-called TIERS, in which the technology developer needs to describe the process and show test results proving the viability of the pathway. In case all is successfully filed to the ASTM-committee (consisting of the OEM's and a wider group of industry stakeholders), the pathway gets an approved Annex under ASTM D7566. HEFA is one of the conversion pathways that has already been approved for use in commercial aviation, and it is accompanied by four others, see Table 1.

Table 1. Overview of SAF technology pathways

Technology	Description	Feedstock	Product	Blend %	ASTM
Fischer-Tropsch to SPK	Converts any carbon-rich material into syngas which is then catalytically converted to jet	Biomass, CO2	Synthetic Paraffinic Kerosene (SPK)	50%	✓
Hydroprocessed Esters and Fatty Acids	Converts oils and fats to hydrocarbons via deoxygenation with hydrogen and cracking	Oils and fats	SPK	50%	✓
Hydroprocessed Fermented Sugars to Synthetic Isoparaffins	Ferments plant sugars to hydrocarbons which are thermochemically upgraded to jet	Sugars	Synthetic Isoparaffins	10%	✓
Fischer-Tropsch to SPK/A	Converts any carbon-rich material into syngas which is then catalytically converted to jet	Biomass, CO2	SPK with Aromatics	50%	✓
Alcohol to Jet	Sugars (from cellulosic materials or syngas) converted to jet through an alcohol intermediate	Sugars, biomass, MSW	SPK	30%	✓
Pyrolysis	Liquefaction of dry biomass to an intermediate biocrude, followed by upgrading to jet fuel	Biomass, MSW			✗
Hydrothermal Liquefaction	Liquefaction of wet biomass to an intermediate biocrude, followed by upgrading to jet fuel	Biomass, MSW			✗

The lengthy and costly procedure to certify a new pathway is a significant hurdle to enter the market. Therefore, being able to use an existing pathway shortens the time to market significantly and is a benefit compared to other biomass pathways such as pyrolysis or Hydrothermal Liquefication, which still need to go through the certification process. At the same time this hurdle pushes technology developers to commercialize their technology in other end-markets, such as diesel or higher value chemicals which do not have such a rigorous certification process.

4.1.3.3 HEFA production capacity

The HEFA technology is currently the only pathway commercially exploited towards SAF. Most of these HEFA facilities focus on the production of renewable diesel (also known as HVO) due to higher yields and market/policy circumstances which will in further detail discussed in the next section.

Figure 3 shows the total installed and planned capacity to treat vegetable oils and fats into renewable fuel products. Where the light green boxes show the installed capacity and dark

[10] The process of quality assurance and certification will be touched upon in more detail in the quality and downstream supply chain section of the business plan.

green capacity that is planned or under construction. As stated, most of these focus on the production of renewable diesel. Only World Energy (formerly known as Altair Fuels) in Los Angeles produces SAF on a continuous basis. However, these facilities could all, with limited investments and slight modifications to the operational settings produce HEFA – SAF as well.

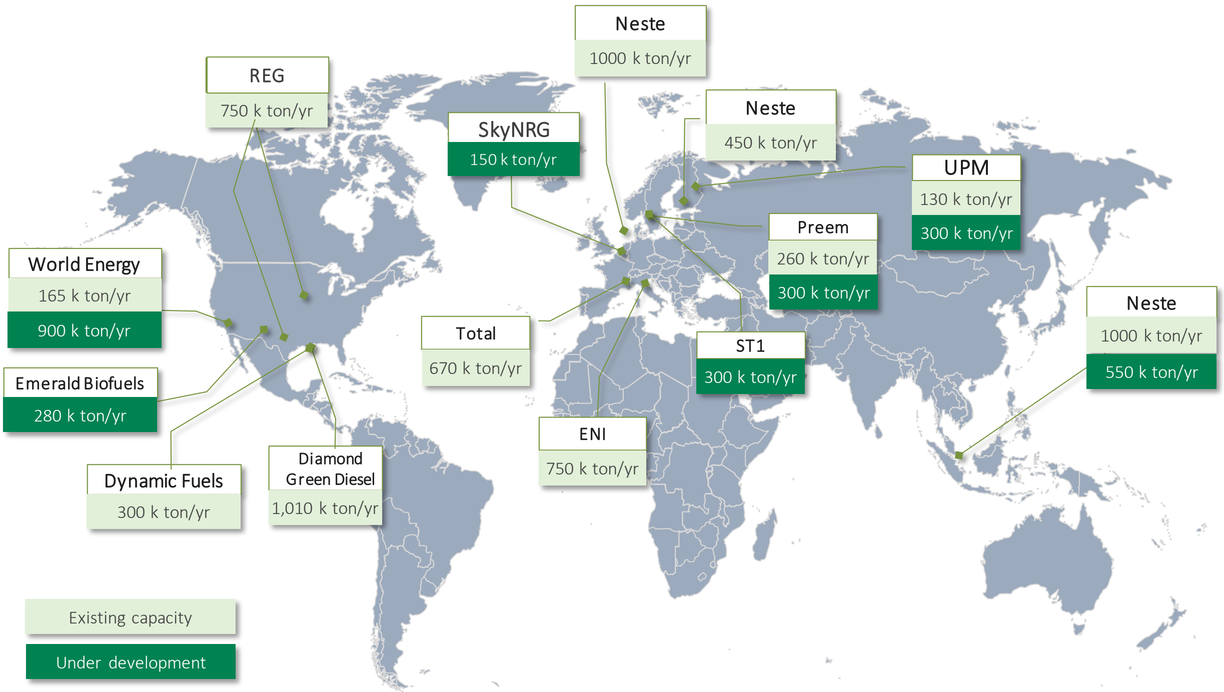

Figure 3. HEFA capacity: existing and under development

4.1.4 SAF demand

4.1.4.1 Initiatives to date

Since the first flight in 2008 by Virgin Atlantic and the first commercial flight on SAF in 2011 by KLM, numerous airlines all over the world have launched SAF initiatives. The industry started the first SAF fuelled flights with initial test-flights, mainly for testing the technical feasibility of SAF and raising awareness. These flights were mostly marketing driven and completely segregated from the fossil Jet A1 supply chain and often even connected to only one engine.

Since 2012 we started to see a shift towards series of flights and further integration of SAF within the fossil the supply chain, in 2016 SAF was introduced for the first time into the hydrant system at Oslo Airport, marking a great improvement in the cost of logistics. Following the commissioning of the AltAir fuels (now: World Energy) in 2016, a switch has been made to continuous supply where KLM and United Airlines operate daily flights from Los Angeles Airport on SAF, making Los Angeles Airport the SAF hub in the world.

The Air Transport Action Group (ATAG), the commercial aviation industry body including airports, airlines, aircrafts manufacturers and others, keeps track of these initiatives[11] and announced in 2017 that over 100,000 flights on SAF had took place since 2008 and more than 30 airlines have performed one or more flights on SAF. Although the 100,000 flights seem to indicate a large uptake of SAF, this also includes the airport on which fuel is put into the hydrant system and allows all aircraft to fly on a small share of SAF. Nevertheless, the industry has developed quickly in its short history. Comparing the 100,000 SAF flights to an annual 10 million flights in 2017 in the EU alone shows the magnitude of the challenge that still lies before the industry.

[11] https://aviationbenefits.org/environmental-efficiency/our-climate-plan/sustainable-aviation-fuel-in-flight/

4.1.4.1.1 Future developments

Besides 'just' purchasing the SAF, airlines are getting more actively involved to enable new production capacity through long term guaranteed off-takes or direct investments. The only commercial scale SAF production facility; World Energy Paramount in Los Angeles, was enabled by off-takes from United Airlines and later KLM. While SkyNRG recently announced to build a 100,000 t dedicated SAF refinery in Delfzijl, The Netherlands coming online in 2022[12]. This plant will also be enabled through investments from the aviation industry (KLM and Schiphol Group) and through long term off-takes from KLM (75,000 tonnes SAF per year). Other initiatives worth noting are the developments of the Red Rock and Fulcrum biorefineries, although these are Fischer-Tropsch based refineries. Red Rock, was enabled through off-takes from FedEx and Southwest each signing for 10,000 t SAF per year. Fulcrum has signed off-takes from United Airlines and Cathay Pacific to enable its investments. Both Red Rock and Fulcrum are expected to come online from 2020 onwards.

4.1.4.2 The European Jet A1 market and potential for SAF uptake

Before diving into the potential of SAF uptake in Europe, we first assess the Jet A1 market, as this will ultimately be the place where SAF will also been taken to air. The European Jet A1 market has seen steady but slower growth than the world-wide market for aviation as it is already developed. Total volume in 2018 was approximately 63 million tonnes in the EU28 countries. Taking a steady 2% growth rate will lead to a fuel demand of 118 million tonnes in 2050, almost doubling the current fuel requirements.

Taking a look at the uptake in the various countries as shown in Figure 4, we see a clear cut between the top six western European countries and the rest of Europe. In these six countries large airports which function as hub systems, with connections towards the rest of the world are located. These hubs are responsible for the majority of the European fuel uptake.

Country	Jet A1 volume metric tonnes (t) in 2012
1. United Kingdom	10.500.000
2. Germany	8.100.000
3. France	6.300.000
4. Spain	4.900.000
5. Italy	3.500.000
6. The Netherlands	3.100.000
7. Switzerland	1.500.000
8. Belgium	1.300.000

Figure 4. Jet A1 uptake per country in 2012

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12 https://skynrg.com/press-releases/klm-skynrg-and-shv-energy-announce-project-first-european-plant-for-sustainable-aviation-fuel/

As stated, the current uptake of SAF is limited to only a few thousand tonnes. To translate the fossil Jet A1 consumption into a potential SAF uptake in the future, we need to make assumptions and we can take several approaches. First there is currently a technical limitation set by ASTM, the maximum blend limit of 50%. For each pathway a maximum blend limit is set when applying for certification. HEFA is limited to a 50% blend with fossil Jet A1, mostly due to the absence of aromatics in the neat HEFA SAF. Test flights on 100% already take place and engine manufacturers expect that in future the need for aromatics could diminish, opening the possibility to fly on 100% blends[13][14]. This means that currently the 50%, shown in Figure 5, is the theoretical limit which could be reached when there is SAF sufficient production capacity, prices are similar or lower than fossil Jet A1 or government mandates the use and uptake of SAF to this level.

It is not likely that from the currently limited uptake, a sudden jump towards the 50% limit will or can take place. The green line therefore shows a more gradually inclining potential uptake forecast scenario. This scenario is still far from set in stone, however looking at the increased interest for SAF stimulating policy in especially the major Jet A1 consuming countries (see policy section) and looking at the necessary CO_2 emission reduction to reach the IATA 50% reduction goals. We could expect an increase of the uptake close to 7% in 2030. In the absence of commercially available alternative technologies, it is likely that most of this volume would come from HEFA based facilities. When more technologies start to commercialize from 2030 onwards the uptake of SAF could rapidly increase towards the 50% (67 million t) in 2050.

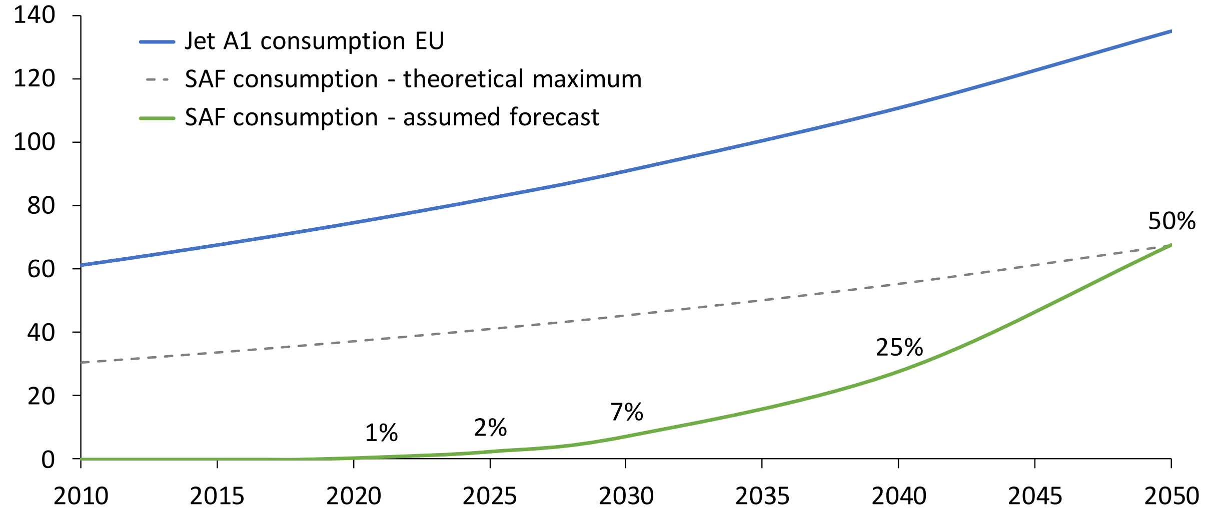

Figure 5. Potential for SAF uptake in EU

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13 https://www.boeing.com/company/about-bca/washington/biofuel-factory-fill-03-08-19.page
14 Beginners guide to SAF, ATAG 2017

4.2 Policy incentives

Policy has been crucial for the development of SAF until now and will be crucial to enable the uptake of SAF in the future. We consider two separate bodies of policy. The first section discusses policy that has a focus to stimulate the increased demand and uptake of SAF. The second section focuses on the sustainability of the SAF pathways, with a focus on HEFA.

4.2.1 Global – CORSIA

On a global level the International Civil Aviation Organisation (ICAO) is developing a market-based measure: the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA is part of ICAO's broader carbon reduction strategy which also covers technological improvements; operational efficiency improvements and; infrastructure improvements.

CORSIA was adopted by the ICAO Member States at the 39th session of the ICAO Assembly in 2016 and aims to achieve the aspirational industry goal of carbon-neutral-growth from 2020 onwards. Average baseline emissions will be based on 2019 and 2020, and any emissions in excess of this amount from 2021 onwards will represent the offsetting requirements for that year. CORSIA will start with a pilot phase, from 2021 until 2023 followed by a first phase from 2024 to 2026, both only apply to states that have volunteered to participate. The second phase, 2027 until 2035 applies to all states with an individual share of international aviation activities above 0.5%. At this stage all EU Member States have agreed to participate in the voluntary phase.

To meet their CO_2 reduction obligation airlines can choose to: 1) buy offsets, 2) use low carbon fossil jet fuel, 3) use SAF. For fuels to be eligible under CORSIA they must meet two sustainability criteria:

- Fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis
- Fuel should not be made from biomass obtained from land with high carbon stock.

Note that these sustainability criteria are quite different from e.g. the sustainability criteria from the RED II or the third-party certification bodies such as RSB or ISCC (please refer to the sections below for more information). In that light CORSIA's sustainability criteria are relatively weak.

Since SAF will basically have to compete with carbon offsets on price it is interesting to compare the cost to reduce CO_2 by either purchasing offsets or by purchasing SAF. First let's consider the cost for carbon offsets. Figure 6 shows the carbon offset price forecast as presented by ICAO's Committee on Aviation Environmental Protection.

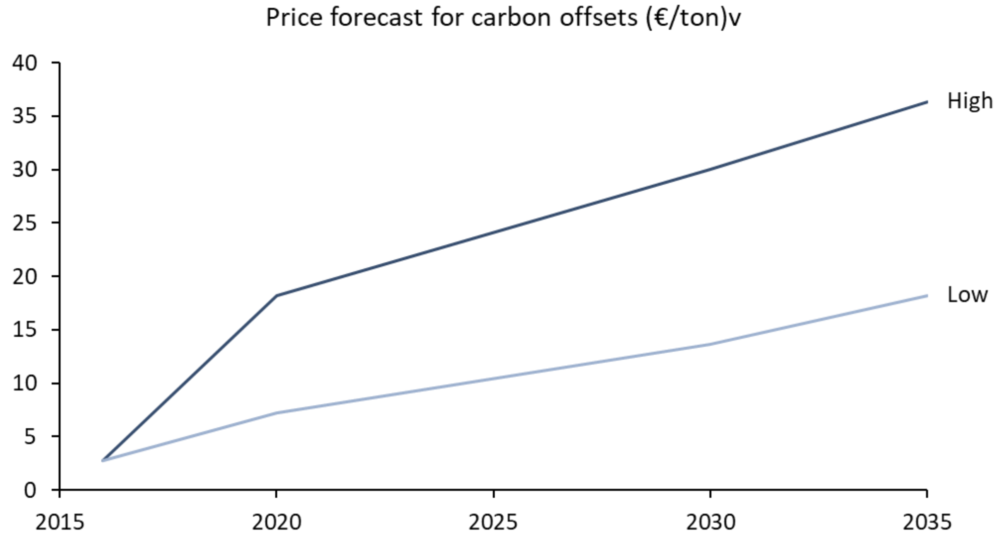

Figure 6. Price forecast for carbon offsets[15].

Table 2 shows what it cost to reduce 1 t of CO_2 by using SAF considering a range of SAF price premiums and CO_2 emission reductions. The TEA has shown that the price premium for HEFA based SAF, excluding policy incentives, is roughly 1100 €/t, assuming 85% CO_2 emission reduction this results in CO_2 abatement cost of € 412. If we compare this to the price of carbon offsets in Figure 6 it's clear that even if we take the "high" scenario it's an order of magnitude more expensive to reduce CO_2 using SAF. Since SAF will have to compete with carbon offsets in the CORSIA scheme we can conclude that this mechanism will not drive SAF demand.

Table 2 Cost to reduce 1 t of CO_2 by using SAF considering a range of price premiums and CO_2 emission reductions

		SAF price premium (€/t)					
CO_2 emission reduction		€ 1,000	€ 1,100	€ 1,200	€ 1,300	€ 1,400	€ 1,500
	65%	€ 490	€ 539	€ 588	€ 637	€ 686	€ 735
	70%	€ 455	€ 500	€ 546	€ 591	€ 637	€ 682
	75%	€ 425	€ 467	€ 510	€ 552	€ 594	€ 637
	80%	€ 398	€ 438	€ 478	€ 518	€ 557	€ 597
	85%	€ 375	€ 412	€ 450	€ 487	€ 525	€ 562
	90%	€ 354	€ 389	€ 425	€ 460	€ 495	€ 531

4.2.2 EU – Renewable Energy Directive II

The Renewable Energy Directive II (RED II) establishes rules for the EU to achieve its renewable energy target by 2030 to continue the fight against climate change and help reach the climate goals of the Paris Agreement. It was preceded in 2009 by the first Renewable Energy Directive which worked towards a target of 20% renewables in Europe's total energy mix by 2020. At least 10% of this target has to be fulfilled through the use of transport fuels from renewable sources.

[15] Source: ICAO CAEP analysis presented at EAG/15 in January 2016

The RED II works towards a target of at least 32% renewable energy by 2030. Note that this is an average EU target and individual Member States might have more ambitious targets. Renewable energy can be produced from a variety of sources including wind, solar, hydro, tidal, geothermal and biomass. The RED includes an obligation for fuel suppliers to ensure that at least 14% of the total final consumption of energy in the (road and rail) transport sector is fulfilled by renewable energy in 2030. With the RED II the EU wants to accelerate the uptake of renewables, ensure the its sustainability and provide long term certainty for investors.

4.2.2.1 Eligible fuels under the RED II

The Fuel Quality Directive and the RED mandate suppliers of renewable fuel, to provide proof of adherence to the sustainability criteria of the RED. For SAF and biofuels in general, this means that a producer of sustainable jet fuel must be able to document compliance to the RED/FQD. This is discussed in more detail in the sustainability section but we'll highlight two things here.

First of all, the RED II specifies GHG reduction thresholds: 65% CO_2 emission reduction for existing biorefineries and 80% for new build biorefineries starting operations from 2026 onwards. Second, the EU differentiates fuels based on the feedstock used for production. Fuels produced from food (crops) and feed are capped at 7% in 2030. The use of wastes and residues is promoted by specifying a minimum level of incorporation for these fuels. Annex IX specifies which feedstocks can be used to produce advanced biofuels. The annex consists of two parts (see Table 3):

- Part A: waste and residue feedstocks which the EU wants to support
- Part B: specific used cooking oil and animal fats, these are limited in volume and are therefore capped

Table 3. Categorisation of feedstocks in Annex IX

Part A	Part B
Algae if cultivated on land in ponds or photobioreactors	Used Cooking Oil (UCO)
Biomass fraction of mixed municipal waste but not separated household waste subject to recycling targets	Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009
Bio-waste as defined in Article 3(4) of Directive 2008/98/EC from private households subject to separate collection	
Biomass fraction of industrial waste not fit for use in the food/feed chain, including material from retail/ wholesale and the agro-food and fish and aquaculture industry, excluding feedstocks listed in part B	
Straw	
Animal manure and sewage sludge	
Palm oil mill effluent and empty palm fruit bunches	
Tall oil pitch	
Crude glycerine	
Bagasse	
Grape marcs and wine lees	
Nut shells	
Husks	
Cobs cleaned of kernels of corn	
Biomass fraction of wastes and residues from forestry and forest-based industries, i.e. bark, branches, pre-commercial thinning's, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil	

Other non-food cellulosic material	
Other ligno-cellulosic material (...) except saw logs and veneer logs	

To incentivize advanced fuels, the RED II double-counts biofuel produced from feedstocks listed in Annex IX. The energy content of these fuels is double counted and thus they also generate double the value in incentives compared to food or feed-based biofuels. This is further discussed in the pricing section at the end of this report.

Since the Bio4A project is focussed on the HEFA technology, the feedstocks listed in part B (UCO and tallow) and potentially also tall oil are the most relevant feedstocks to consider. The sustainability requirements of RED II and their implications for future HEFA facilities is treated in more detail in section 4.2.4.

4.2.2.2 Aviation opt-in

The RED II does not include an obligation for the use of renewables in the aviation and maritime sector. However, Fuels used in these sectors can opt in to contribute to the 14% transport target. This means that in calculating the share of renewables in transportation aviation and maritime are only counted for in the numerator but not in the denominator, see Figure 7.

To account for the higher production cost for sustainable aviation and maritime fuels compared to fuels for road transport fuels, fuels used in these sectors will count for 1.2 times their energy content. However, the opt-in for aviation (and shipping) is not mandatory each EU member state may decide to adopt it and the same holds for the multiplier for aviation and marine. Hence, the transposition of the RED II into national legislation is critical for the viability of SAF. This will be further discussed in the deliverables on RED implementation.

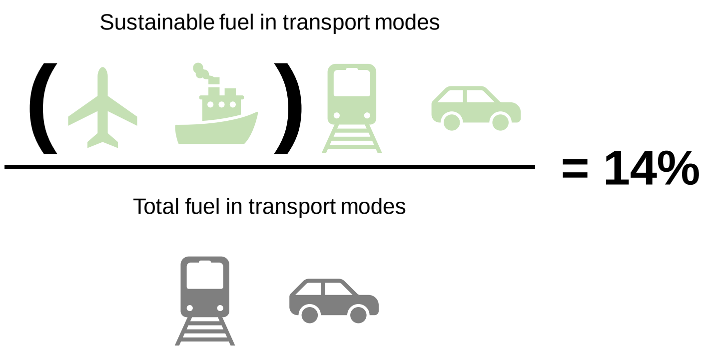

Figure 7. Voluntary inclusion of aviation in RED II

4.2.2.3 An example the implementation of the RED in The Netherlands

In the implementation of the RED (I), the Dutch Government chose to implement a flexible system allowing fuels suppliers to meet their obligation in the most cost-effective way. This means that they can either supply renewable fuels or buy credits from others that have supplied a surplus of renewable fuels. These credits are called “HBE’s”, HBE’s are generated when renewable fuel is supplied and represent 1GJ of renewable energy. At the end of the year, fuel suppliers have to show compliance by handing over a number of HBE’s equal to their obligation[16].

The road and rail sector are the only mandated sectors that have to comply with the 10% renewable energy target of the RED. However, the Netherlands was the only Member State that chose to create an ‘opt-in’ for aviation. This means that when SAF is supplied to the Dutch

[16] https://skynrg.com/wp-content/uploads/2019/03/Publications-The-voluntary-RED-opt-in-for-aviation-biofuels.pdf

market, the SAF (combined with a Proof of Sustainability (PoS)) can generate HBE's within this system. These HBE's can then be sold to obligated parties and thereby contribute to the targets of the mandated sectors under the RED/FQD.

Although the implementation of the RED II is ongoing, the HBE system with the opt-in for aviation will largely remain. The RED II does require some changes to account for the new categorisation of fuels based on Annex IX. The Dutch authorities differentiate three different types of renewable fuels with corresponding HBE categories:

1. HBE Conventional for food/feed-based fuels
2. HBE Advanced for fuels produced from feedstocks listed in Annex IX part a
3. HBE Other for fuels produced from feedstocks listed in Annex IX part b

The Figure 8 below shows the categorisation of renewable fuels and HBE's.

RED II		Dutch system	
Feedstock type	**Feedstock example**	**HBE type**	**Single/double counting**
Conventional	Rapeseed oil	HBE Conventional	Single
Annex IX – Part A	Municipal Solid Waste	HBE Advanced	Double
Annex IX – Part B	**Used Cooking Oil**	**HBE Other**	**Double**

Figure 8. Overview of HBE categories per feedstock type under RED (II)

The renewable fuels from the advanced and other category are counted for twice their energy content and thus they create double the amount of corresponding HBE tickets. Note that renewable fuels that are double-counted and used in aviation will be counted for 1.2 * 2 = 2.4 times their energy content. Following the RED, the obligated companies in the road and rail sector must produce a minimum amount of these fuels. The RED II demands that in 2030 at least 3.5% of the total amount of energy produced by the mandatory parties comes from the production and trade of advanced biofuel within the Netherlands.[17] As this is a challenging target, and the feedstock list of Annex IX, Part A is limited, there is and will be a strong demand for these fuels.

The HBE Conventional tickets can be generated when the fuel, with the PoS, is produced from (energy) crops. These feedstocks are the so-called 'first generation' feedstocks. As these feedstocks can often be used for food and/ or feed, the EU wants to eliminate them as a feedstock for biofuel which energy content may count towards the renewable energy targets. For the start of the RED II, a maximum of 7% of the total share of renewable energy from the transport sector may come from biofuels produced from food and/or feed crops. This maximum share will slowly decrease to 0% in 2030.[18]

The HBE Other category stimulates fuels produced from feedstocks listed in the RED (II) Annex IX, Part B (these are animal fat and Used Cooking Oil type of feedstocks). Also types of feedstock which aren't included in the Annex IX or are excluded from the HBE Conventional category may be included in this category. In the case of Bio4A, a HEFA facility taking in waste oils and fats will fall under this category. In some cases, renewable electricity may also count towards the renewable energy target, in which case it is included in this category.[19]

[17] Annotation 2, page 125
[18] Annotation 2, page 126
[19] Wet Milieubeheer, article 9.7.4.6.

4.2.2.4 Expected value of the HBE's

The value of an HBE should equal the cost of a GJ of renewable fuel as suppliers have the choice to either produce or buy the physical product or the certificate. This price has increased over the past years, amongst other because the increasing blend mandates require for the incorporation of the (more costly) renewable diesel as the biodiesel (FAME) blend wall has been reached. But there are more factors that determine the value of the HBE (such as the feedstock cost) and thus the HBE price fluctuate. Looking at the historic developments we can conclude that the HBE price has increased from € 4.50 in 2014 (when HBE's were called bio tickets) to € 10 per HBE on average in 2019. Due to these historic developments it is expected that the price per HBE will keep increasing as policy incentives will get stricter and obligations will get higher.[20]

The value of the HBE will be necessary to bridge the price gap for SAF, discussed in more detailed in the pricing section of this report. One ton of SAF consists of 43.5 GJ[21], under the RED, 44 GJ is assumed for jet fuel, which can be counted 1.2 times due to the aviation multiplier plus double counting if produced from annex IX feedstock. Taking the 2019 HBE values this would result in 44*10*1.2*2= € 1056 resulting from the generation of HBEs per ton of SAF.

4.2.3 EU's Emission Trading Scheme

The Emission Trading Scheme (ETS) covers selected industrial sectors such as power and heat generation and energy-intensive industries. In 2012 the EU decided to include emissions from aviation in the ETS. Initially this included emissions from all flights departing from an EU airport but after strong opposition from the aviation industry, its scope was reduced to intra EU flights only. The EU only agreed to this under the condition that the CORSIA would be established in such a way that it would realize the required carbon reduction. If not, the EU will again include emissions from all flights leaving the EU under the ETS.

ETS is a “cap and trade” system, where the cap (GHG emission allowance) is gradually reduced over time, in alignment of the overall GHG targets of the participating partners. The EU became operational in 2005 and has since been a cornerstone of the EU GHG mitigation instruments, covering today about 45% of the total EU emissions.

ETS covers the European Economic Area (EEA) (including Iceland and Norway as EFTA members). Like industrial installations covered by the system, airlines receive tradeable allowances covering a certain level of CO2 emissions from their flights per year.

The current price of EU ETS allowances (the right to emit 1 t of CO_2) is roughly €25/t CO_2. Although this is significantly more than the price of carbon offsets, it is still an order of magnitude more expensive to reduce CO_2 with SAF. As shown in table Table 2 the cost to reduce 1 t of CO_2 through the use of SAF is estimated at € 412 (assuming a price premium of €1100/t SAF and 85% CO_2 reduction.

4.2.4 National – Mandates

Currently, the offtake of SAF by airlines is largely a voluntary market. This landscape is however slowly changing. Especially within Europe, more and more countries consider implementing a mandate in their national legislation. These mandates often take a consumer-based approach, forcing the fuel supplier to substitute an X percentage of jet fuel supply by SAF.

There are different policy mechanisms behind this. In Norway, which is currently the only country in Europe that officially introduced their mandate structure into national legislation, fuel suppliers

[20] The price developments of the HBE system, from 2015 onwards, can be found at: https://www.emissieautoriteit.nl/onderwerpen/rapportages-ev-2018/hbe-rapportages/publicatie-hbe-rapportage
[21] Vreuls, H.H.J. (2015). The Netherlands: list of fuels and standard CO2 emission factors. Ministry of VROM, page 5.

are demanded to substitute fossil jet fuel with <0.5% advanced SAF from 2020 onwards.[22] A more indirect approach is taken in Sweden, where fuel suppliers will have to reduce the CO_2 emissions per unit of jet fuel, by blending in SAF. In this proposed emission reduction obligation, the reduction percentage increases yearly (starting at 0.8% in 2021 and increasing to 27% in 2030) and fuel suppliers will be fined per kg CO_2 emitted above the reduction obligation.[23] An overview of mandates is provided in Table 4.

Table 4. (Proposed) SAF mandates throughout Europe

Country	Mandate proposed	Expected SAF volume		
		2020	2025	2030
Norway	The Norwegian government is the first to create a mandate on the aviation fuel market. They created a mandate on all jet fuel consumed, focusing on advanced feedstock sources.	0.5% (5000 t)	-	30% (300,000 t)
Sweden	Looking at following the Norwegian example, proposed but not yet confirmed in governmental voting.	1% (11,000 t)	5% (55,000 t)	30% (330,000 t)
Finland	A blending obligation for SAF was proposed in the new government program as part of the target to be carbon neutral as a country by 2035.	-	-	30% [in 2035] (300,000 t)
Spain	Government intends to create a SAF mandate in its proposed climate policy.	-	2% (110,000 t)	-
France	The French government is developing a roadmap for SAF uptake in collaboration with industrial players. A mandate was mentioned by the ministry of transport, which is expected to materialize late 2019.	-	2.5% (200,000 t)	5% (400,000 t)
Netherlands	Not formally proposed, but rumours suggest the government will follow the industry target.	-	-	14% (574,000 t)

With these incentives in place, the aviation sector is forced to act and guaranteed volumes will be supplied to the aviation market. In this way, the implementation of mandates into national legislation will lead to the certainty of SAF demand and can therewith be an important reason for investors to invest in the sector. A possible risk in mandates lies with the fact that stimulating the sector could also have negative side effects, when e.g. pushing an already limited feedstock base. Therefore, countries might choose to exclude certain feedstocks, like virgin oils with a risk on land use change, but also waste oils and fats could be excluded from the mandates to avoid indirect effects. This could impact the opportunity for future HEFA development based on these mandates. The ongoing translation of these proposals into national legislation will determine whether feedstock requirements will indeed be a challenge and whether low-ILUC feedstocks could be allowed as an alternative for HEFA based facilities.

Another risk with mandates, lays with the fact that countries will look at the possibilities to use already existing renewable diesel facilities for the production of SAF in the first few years, especially if the mandates are coming into force over the next 2 – 5 years. This will not create additional SAF production capacity but will merely shift the production of renewable diesel into SAF. To overcome this, it is important for EU member states to focus on pushing for additional production capacity when considering a mandate.

[22] For a public statement on the Norwegian mandate, you can visit http://biomassmagazine.com/articles/15657/norway-to-implement-biofuel-mandate-for-aviation-fuel-in-2020

[23] The Swedish plans are discussed in https://ilbioeconomista.com/2019/03/14/sweden-will-introduce-a-greenhouse-gas-reduction-mandate-for-aviation-fuel/

4.3 Sustainability

4.3.1 Frameworks and trends

It's clear that the use of SAF, along with other efficiencies in operations and aircraft design, is intended to reduce the industry's growing share of greenhouse gas emissions and lower the overall climate impact of aviation.

However, without proper compliance of the criteria verified under a robust sustainability certification scheme, some of these fuels risk having negative social and environmental impacts. Examples of such could be negligible greenhouse gas emissions reductions, reduced food security through the conversion of food-producing land to feedstock production, environmental degradation from deforestation, and unsustainable soil and water usage.

The goal of achieving net carbon emission reduction is the main motivation for using sustainable aviation fuel (SAF) in order to meet the aviation industry's ambitious climate goals. However, simply deploying any form of alternative fuel on aircraft does not necessarily reduce overall carbon emissions. The fuels used must demonstrate a net carbon reduction through lifecycle analysis (LCA) as well as other sustainability metrics related to feedstock and social issues.

Though the term sustainability is commonly used, there is currently no internationally agreed definition of what constitutes to SAF. There are several sustainability initiatives worldwide, with varying definitions. Thus, the following section will seek to outline what aspects of sustainability that should be included in the assessment of sustainable biofuels for aviation.

4.3.2 European Union

Biomass use for energy purposes has increased significantly over the past years due to a substantial amount of countries turning to renewable energy sources with the aim to decrease the use of fossil jet fuel. Together with an increasing use of biomass, there is an increasing amount of data informing society that the rise in demand for biomass is accompanied by social and environmental impacts and potential risks in many biomass producing countries. Debate on biomass sustainability has risen in the society and biofuel policies. The political debate in the European Union about the sustainability of biomass for energy use resulted, among others, in the inclusion of sustainability criteria in 2009 in the Renewable Energy Directive (RED) and later on in its RED II in 2019. The RED II defines a series of sustainability and GHG emission criteria that bioliquids used in transport must comply with to be counted towards the overall 14% target of fossil fuel substitution and to be eligible for financial support by public authorities. Fuels used in the aviation and maritime sectors can opt-in to contribute to the transport target but are not subject to an obligation (see policy section 4.2.2.2). The contribution of non-food renewable fuels supplied to these sectors will count 1.2 times their energy content.

Some of these sustainable criteria are the same as in the original RED, while others are new or reformulated. In particular, the RED II introduces criteria related to sustainability for forestry feedstocks as well as GHG criteria for solid and gaseous biomass fuels but there is no specific regulation around the use of SAF. Another important criterion which was defined is regarding indirect land use change (ILUC). In March 2019 the Commission adopted the Delegate Regulation (EU) 2019/807 defining which ILUC feedstocks can count towards this target, and it set a limitation to 2019 consumption levels in each EU Member State in period 2019-2023, phasing down to zero by 2030.

However, all of these criteria are focused on environmental issues such as greenhouse gas saving and nature protection, not including mandatory social criteria, related to social and economic impacts such as decreasing food security, labour rights or loss of land.

4.3.2.1 Overview voluntary schemes and certification

Under the RED and FQD, it is mandatory for companies who wish to market their products as sustainable, to provide proof of adherence to the sustainability criteria of the directive. For the biofuel industry, this means that a producer of SAF must be able to document compliance to the

RED/FQD not only in their own production processes, but throughout their whole value chain, i.e. the sustainability of suppliers, biomass producers, etc. Voluntary schemes are developed and managed by sustainability certification companies that evaluate value chains according to the RED/FQD requirements. Thus, companies participating in the value chain for biofuels for aviation can use certification by voluntary schemes as proof of sustainability requirements. Since RED was promulgated 20 voluntary schemes were approved but as of July 2019 only 15 of them are in force covering multiple feedstocks and crops[24]. These voluntary schemes are an instrument under RED to verify the sustainability of biofuels to be counted towards the EU target but should be updated to new criteria under REDII. The Commission plans to start the process of recognition of the voluntary schemes for covering the revised RED II sustainability criteria during the first half of 2020.

Some of these systems exist on a national level, and others are internationally recognized and applicable. As these systems have been developed with different interests and priorities (governments, NGOs, companies), the scope, approach and complexity varies from scheme to scheme (Scarlat and Dallemand, 2011; Souza and others, 2015).

Voluntary schemes verify first of all the compliance with the EU's biofuel sustainability criteria but several schemes take additional factors into account, such as soil, water, air protection and social criteria. Any social criteria recognized under a particular scheme are considered as additional in the framework of RED. Generally, in bioenergetic systems, the social impacts are more relevant during the agricultural stage, involving labour conditions, labour rights, food competition, and others. Employment generation and salaries along the supply chain must also be considered.

From all the approved voluntary schemes, only 8 address social matters by means of implementing social criteria. Given that there are no binding obligations regarding socio economic requirements under RED, each voluntary scheme has established its own defined criteria. In addition, those schemes addressing social sustainability use different approach and scope. Worldwide framework sustainability schemes as RSB, CSBP, RSPO, RTRS and Bonsucro, address social sustainability wide and deeply, while those RED schemes (ISCC or those worldwide schemes adapted to RED) show weaker provisions and topics not addressed. In addition, changes are to be expected in all voluntary schemes due to publication of new requirements in REDII and they will need to update these schemes to these new criteria.

Focusing on the SAF sector, RSB is a voluntary scheme which has worked on the Alternative Fuels Task Force of CORSIA (RSB, 2018). Within this work they focused on developing specific requirements for SAF, RSB is therefore well placed to support their implementation. RSB tools include a greenhouse gas calculator that covers the full scope of the CORSIA methodology from agriculture and transport to processing. To support airlines with meeting their reporting requirements, RSB provides Chain of Custody certification that ensures that information necessary to fulfil CORSIA reporting requirements.

Furthermore, ISCC scheme is also commonly used in terms of valid certificated on use. It shows higher level of verification of human and labour right principle. The aviation industry has shown interest in ISCC as a scheme for SAF certification.

A final option would be to fulfil the specific SAF sustainability requirements by creating and implementing a new certification standard for aviation fuel, this idea was discussed in a stakeholder workshop (Ecofys, 2015), but was rejected by the aviation industry since efforts would be higher than trying to adapt current standards.

[24] ec.europa.eu/energy/en/topics/renewable-energy/biofuels/voluntary-schemes

4.3.2.2 National regulation

4.3.2.2.1 United States

The RFS program is a USA national policy that requires a certain volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil or jet fuel.

For a fuel to qualify as a renewable fuel under the RFS program, EPA must determine that the fuel qualifies under the statutes and regulations. Among other requirements, fuels must achieve a reduction in greenhouse gas (GHG) emissions as compared to a 2005 petroleum baseline. EPA has approved fuel pathways under the RFS program under all four categories of renewable fuel. Advanced pathways already approved include ethanol made from sugarcane; SAF made from camelina; cellulosic ethanol made from corn stover; compressed natural gas from municipal wastewater treatment facility digesters; and others.

Jet fuel is not mandated under the RFS2, however SAF fuel can be counted towards the targets. So SAF which is produced under this legislation must fulfil the previously explained sustainable requirements. These criteria are based on GHG emission savings and impose restrictions on the type of feedstock used to produce renewable fuel and type of land used to grow these feedstock.

4.3.2.2.2 Brazil

In Brazil air transportation is growing rapidly, higher than the global average. Brazil is already one of the largest countries in terms of domestic flights, while the industry keeps on growing.

Even though this growing demand there is no binding SAF sustainability policy in Brazil. Nonetheless Brazil has joined the CORSIA scheme in order to promote SAF use in its flights and is part of different initiatives aimed at stimulating SAF fuel in Brazil such as: Sustainable Aviation Biofuels from Brazil (SAAB) and Brazilian SAF Fuel Platform. Since there is no national scheme for SAF, Brazil will not be studied in the following section for comparison purposes.

4.3.2.3 Comparison between standards

In order to have a global overview of the status of different sustainability schemes a review of the most common standard or regulations used in the biofuel sector is provided. As stated previously, the European legislation does not have a binding target for SAF uptake, however due to the option of using SAF under the RED II we will review this piece of legislation. Furthermore, we picked the ISCC and RBS schemes since they are the most commonly used in the biofuel sector, and some of them are already used for SAF verification.

Standard-Regulation		RED II	ISCC	RBS	RFS	CORSIA
Scope						
Geographical coverage of scheme		EU	EU	EU	USA	Global
Feedstock		Multiple agricultural feedstock, UCO, and agricultural residues	Multiple agricultural feedstock	Multiple agricultural feedstock	Multiple agricultural feedstock, MSW, UCO and agricultural/forestry residues	Multiple agricultural feedstock, MSW, UCO and agricultural/forestry residues
Sustainable criteria						
Environmental	GHG saving	✓	✓	✓	✓	✓
	Land criteria	✓	✓	✓	✓	✓
	Biodiversity protection (soil, water, ecosystems..)	✓	✓	✓	✓	✓

Social	Labour right and working conditions	X	✓	✓	X	X
	Land use right	X	✓	✓	X	X
	Food security	X	X	✓	X	X
Economic						
	Economic stability	X	X	X	X	X

Table 5 Comparison sustainable schemes-standards

4.4 SAF Pricing

The pricing of SAF is not a straightforward process. This is mostly since the uptake of SAF is still very much limited, approximately 0.01% of the total jet fuel demand in the world is fulfilled by SAF supply. Of which most is fuelled in Los Angeles near the refinery of World Energy. The market in Europe is even smaller. As a result, the SAF market is not a commodity market, it's in-transparent and characterized by over the counter trades. Because of these dynamics it is impossible to come up with a 'price for SAF'. The one thing that is possible is to discuss the market dynamics and focus on the price formation. This section starts with a quick view on the fossil jet A1 price, followed by a market approach to estimate the SAF price, which can be compared with the results of deliverable 5.1 in which a cost-assessment is done on the production of HEFA-based SAF.

4.4.1 Fossil Jet A1 price

For reference it is useful to consider how conventional jet fuel pricing works. Figure 9 shows the historic Jet A1 prices in the Amsterdam, Rotterdam, Antwerp (ARA) region. As can be seen the price of Jet A1 has fluctuated heavily in recent years between 300 and 800 €/t. Airlines, will purchase fuel based on a variety of contracts, these contracts can both be based on this shown 'spot' price in a certain region or on 'future' prices. In general, the future prices are more expensive than current spot prices, but due to the longer term of the contract, airlines can favour these contracts as they can cover their exposure to sudden price increases. In 2019 the average price fluctuated around 600 €/t jet fuel. In very competitive markets and/or for large volumes airlines may be able to secure discounts on these indexed prices.

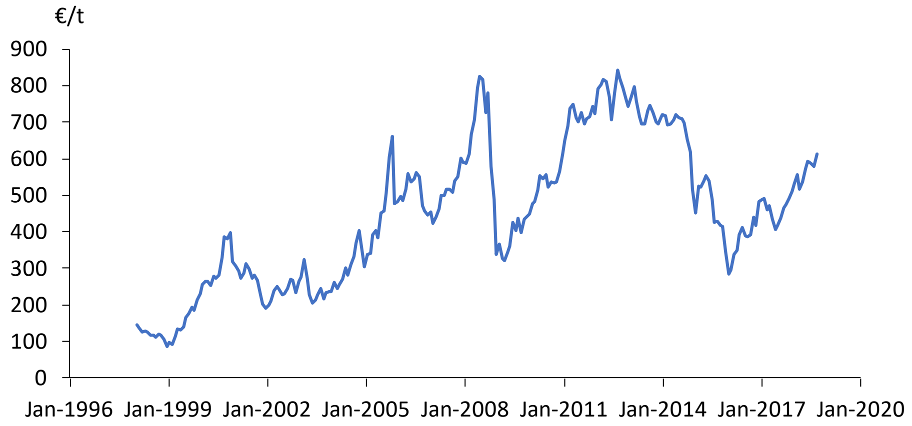

Figure 9. Fossil jet A1 historic prices (source: Platts)

4.4.2 SAF pricing

SAF pricing works completely different, due to the limited capacity there are only a few suppliers of SAF. This creates a situation in which contracts are mostly based on 1 on 1 deals and no price index or data on historic pricing is available. Pricing in different contracts may vary considerably as there is no fixed price structure. This means that SAF contracts can be based on a contract to cover cost (mostly feedstock) + a premium for the scarcity of the fuel, or a contract based on the fossil Jet-A1 price + a premium. For HEFA, which is the only available SAF at the moment, this premium is significant and counts towards a multiple (roughly 2-4) of the Jet-A1 price.

To get a better view on the SAF pricing, besides this very high-level estimate, there is a multitude of approaches possible. The first is to take a bottom up approach with a techno-economic assessment. This is done in the project as part of deliverable 5.1. Due to the nature of such a TEA, there will be an uncertainty range as assumptions are taken for CAPEX and OPEX values, because these values are not in the public domain. Also, certain assumptions vary heavily depending on the local circumstances. We will, for the sake of completeness do this exercise as part of the business case assessment in the next chapter. Below we will explore a market-based approach to determine the SAF price of HEFA based fuels under the Renewable Energy Directive.

4.4.3 The value of SAF in the EU under the Renewable Energy Directive

As an alternative to (academic) bottom-up analysis we can calculate the revenue SAF could generate in the context of European legislation. This is not necessarily the same as the SAF market price, but it gives a good indication of what a minimum price could be. To do this, we take the Dutch policy system in which SAF is allowed to count towards the road transport sustainability targets. When calculating the revenues, we differentiate between the fossil value of the fuel (the jet fuel price) and the green premium which includes the revenues from the RED incentives scheme (see policy section for more detail). The value of a HBE fluctuates to cover the difference between the fossil fuel price and the production costs for the biofuel alternative, currently this mechanism holds for the production of renewable diesel. Figure 10 shows that the estimated SAF price would be just below 1700 €/t in the current situation, if we assume a double-counting feedstock (annex IX, RED-II) and take the average HBE value over 2019 (10 €/HBE) and the aviation multiplier (1.2). It is important to keep in mind that the HBE value is a fluctuating value, which adjusts according to market circumstances such as feedstock price, availability of production capacity, etc.

Vegetable oils are currently not included in the list of Annex IX feedstocks, so if these are used for the SAF production this fuel is excluded from double counting. This is shown in the left graph in Figure 10. The both graphs show the value of the SAF when produced and put in the system in the Netherlands. Market prices can deviate from this as the market players can decide to charge higher prices to fill in the mandates. This is especially the case in a market where only few players are active.

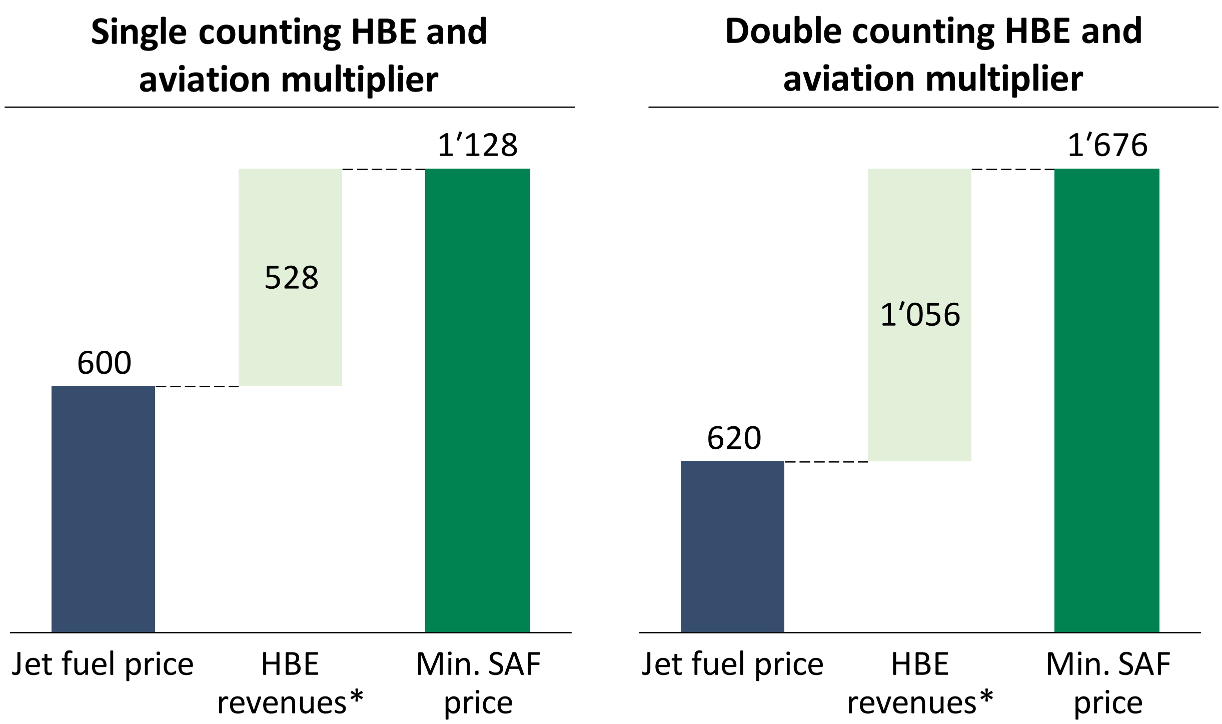

Figure 10. Calculated minimum SAF prices based on the conventional jet fuel price and the revenues from sales of HBE's certificates in two scenarios (€/t). * Based on HBE average price in 2019 (10€/HBE) 44GJ per t of jet fuel and including the 1.2x multiplier.

Although these values are similar to the costs estimated in the deliverable 5.1 it must be noted that only very limited amounts of SAF have been supplied in the Netherlands, or anywhere else in Europe. This is a strong indicator that the current revenues are insufficient to enable for the production and supply of SAF. This especially holds when compared to HEFA-diesel production, which can yield similar revenues with lower production costs and higher yields.

5 Conclusion

In this report we have identified the most important market dynamics around Sustainable Aviation Fuels. Below we will summarise the dynamics according to three categories.

1. SAF demand and price

The industry has set ambitious sustainability targets, however at this stage they are just aspirational targets and by themselves not sufficient to drive change. It's clear that policy frameworks are essential to achieve large scale market penetration. In an environment whereby airlines mainly compete on price, the current SAF economics are the main barrier for usage.

Although there is no public pricing information available for SAF, an estimate of the value of SAF can be made under the RED I and future RED II policy. The analysis shows that the estimate revenue for waste based SAF is likely to be around 1200 – 1700 €/t in Europe (post 2021). The implementation of the RED II in each member states will be very important as this will determine whether certain feedstocks will qualify for double counting and whether SAF can count towards the road transport sector mandates.

The techno-economic assessment (D5.1) will use a cost-based approach to determine the minimal fuel selling price necessary to break even in a general HEFA facility based in EU market circumstances. The abovementioned values will serve as benchmarks to determine the competitiveness of the pathway. The market element which is not taken into account is the willingness of airlines to pay a premium for SAF. In specific cases, it's feasible to get a premium from the airlines for fuels that have a very good sustainability profile and/or can generate additional value such as exposure or risk mitigation for future policy.

2. Interaction with other markets

The HEFA pathway can focus its main product to be diesel or jet fuel, based on the chosen technology and settings of the pathway. The yield towards diesel is generally somewhat higher, while under the current circumstances the incentive values are the same, therefore almost all HEFA facilities are operating in diesel mode. To create a more level playing field, the European Commission decided to implement the multiplier for aviation. Together with the multiplier for aviation marine fuels also got a 1.2 multiplier within the RED-II legislation. Due to the high quality requirements and therewith challenging process conditions for SAF production, it could be the case that operators will push the renewable diesel production mostly into the marine market. This is to be seen in future development of the RED II and as this will depend on the feedstock markets will be discussed in D5.3 as well.

Another limitation in scaling up is the availability of sustainable feedstock. Aviation is known for having high sustainability and quality standards. One of the risks of scaling the market too rapidly is that we lower these sustainability standards to get competitive. This can cause serious backlash which would be harmful for this nascent industry. We therefore need to focus on feedstock diversification, both on the vegetable oil side (low-ILUC vegetable oils) as well as sustainable waste and residues,

Another hurdle for the aviation industry compared to other markets is the ASTM certification. Although this hurdle doesn't apply to the HEFA case, as it is already certified, it does influence the ability of new technologies to come online and supply the aviation industry. This is because the certification hurdle pushes technology developers to commercialize their technology in other end-markets, such as diesel or higher value chemicals which do not have such a rigorous certification process.

3. Policy targets and sustainability

Although a multitude of policies exist to push for sustainable fuels in transport, there is not yet a clear push for SAF in Europe. Instruments such as CORSIA can help industry to achieve GHG emission saving and reach targets to grow carbon neutrally, however this will not stimulate the uptake of SAF. Due to the challenging economics of SAF compared to fossil Jet-A1, stricter policy will be needed to kick-start the market. At the same time, due to the absence of a legally binding target for SAF there is no mandatory sustainable criteria which should be applied to SAF. Due to the sensitivity of the current HEFA-based feedstocks in the form of vegetable oils, it is important to create clear sustainability guidelines for SAF uptake once policy becomes more prescriptive for aviation. Besides GHG emissions it is important to include more indirect factors such as social and economic sustainability.