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# **Sustainable aviation fuels:** mobilising biomass resources and ramping up low-carbon electricity production to reach the ReFuelEU targets

## Executive summary

With the adoption of the ReFuelEU regulation, a clear trajectory has been set up in Europe for the incorporation of SAF in aviation fuels with a target of 70% of SAF in 2050, including 35% in the form of synthetic fuels of non-biological origin.

Reaching these targets and achieving further developments in aircraft design and traffic management will make it possible for the aviation sector to no longer rely on fossil fuels. These objectives are ambitious, especially given that air transport is more difficult to decarbonise than other sectors such as road transport or buildings, but they can be achieved as highlighted by the Commission's preliminary analysis and impact assessments.

EdEn welcomes the adoption of this regulation as well as the adoption of other legislative initiatives that will support the decarbonisation of aviation, such as the EU-ETS directive and the RED directive.

The priority is now to define an industrial strategy for the development of a SAF production capacity that could cover the needs of the EU aviation sector and make it possible to reach the ReFuelEU objectives, without relying excessively on imports. In addition, ensuring that this new European SAF industry remains price-competitive will be key in order to maintain a level playing field between EU and non-EU actors.

The first step of this industrial strategy should be to assess the availability of the necessary resources for the production of SAF and to develop the infrastructure that will provide these resources – essentially biomass and low-carbon electricity – in the quantities and timing required under the ReFuelEU regulation.

In this perspective, this paper aims at assessing the biomass and energy needs required for the implementation of the ReFuelEU regulation and the various possible scenarios that could be followed to achieve the targets.

**Two alternative scenarios are considered:** one is consistent with the scenario initially proposed by the Commission in the ReFuelEU impact assessment, the other is based on a trade-off between reduced biomass needs – as biomass could become a major bottleneck in SAF production – and an increase in low-carbon electricity consumption. A third scenario explores the impact of a blending mandate of 85%, as proposed by the European Parliament during the negotiation phase of the regulation.

The results of this assessment highlight the planification efforts that Member States should undertake, under the coordination of the Commission, in order to reach the adopted targets.

**These results lead to the following recommendations:**

- **In regards to biomass, given the limited available resources, the scenarios associated with a more reduced biomass consumption and an increased electricity use should be prioritised;**
- **The aviation sector should be given priority for the use of biomass resources as most other sectors have access to other solutions, such as direct electrification, for their decarbonisation;**
- **In order to ensure that enough low carbon electricity is available for the production of e-fuels, planning ahead the development of adequate means of production, likely a mix of renewable forms of energy and of new nuclear power plants, is necessary.**


### *En route* for Fit for 55

The EU has embarked on an ambitious program to achieve climate neutrality by 2050. The first stage, called "Fit for 55", aims to reduce net greenhouse gas emissions by at least 55% by 2030 compared to 1990. In this framework, two regulatory texts are crucial for the aviation sector:

- **the European Emissions Trading System (EU-ETS)** and the phasing out of free $CO_2$ allowances for aviation;
- **the ReFuelEU aviation regulation** that will make it mandatory to increase the use of sustainable aviation fuels (SAF) by setting blending mandates of SAF increasing from 2% in 2025, 6% in 2030, 20% in 2035, 34% in 2040, 42% in 2045 to 70% in 2050.

This paper addresses this second challenge through an assessment of the availability of the biomass and electricity required to decarbonise the air transport. It uses the assessment carried out by the European Commission in its impact study accompanying the initial proposal for the ReFuelEU regulation and also relies on further evaluations carried out by ONERA, the French Aerospace Lab.

## Various types of SAF requiring various types of feedstocks

The initial ReFuelEU regulation draft recognised several types of SAFs:

- **Aviation biofuels**, which can be divided into two categories:
  - **Biofuels produced through conventional pathways (typically HEFA)** from vegetable oils and waste lipids, i.e. used cooking oils and animal fats classified in Annex IX Part B of the RED II directive. HEFA is the least expensive pathway and is industrially mature. But the availability of feedstocks compliant with the RED requirements is a strong limiting factor.
  - **Advanced biofuels**, classified in Annex IX Part A of the RED II directive and produced from lignocellulosic feedstocks (e.g. agricultural or forestry residues, grass materials), algae, bio-waste feedstock (municipal solid waste) and others. Advanced biofuels can be produced through the gasification + Fischer-Tropsch (FT) or the Alcohol-to-Jet (ATJ) pathways. These pathways may lead to higher production than HEFA but are currently only at demonstration phase.
- **Synthetic aviation fuels** (i.e. Power-to-Liquid fuels or e-fuels) produced through the conversion of $CO_2$ resources into CO, followed by Fischer-Tropsch reactions based on low-carbon hydrogen produced by the electrolysis of water. For the pathway to be carbon neutral, the $CO_2$ can be either captured from biomass thermal process (BECCS) or directly captured from the air (DAC).

During the negotiation phase of the regulation, the definition of SAF was extended to cover additional types of fuels:

- **Biofuels other than biofuels produced from the feedstock listed in Part A or B of Annex IX of the RED II directive**, with the exception of biofuels produced from "food and feed crops", subject to certain sustainability criteria and within the limit of 3% in the calculation of the share of SAF in the aviation fuels;
- Under certain conditions, **recycled carbon aviation fuels**, using $CO_2$ captured from industrial processes via PSC (Point Source Capture);
- **Aviation hydrogen**, either renewable or low carbon, which is not strictly speaking considered as SAF but is taken into account in the calculation of the share of SAF in the aviation fuels.

This document adopts a simpler classification:

- **Biofuels**, i.e:
  - **HEFA** i.e conventional biofuels produced through the HEFA pathway;
  - **Advanced biofuels**, called **BtL** (Biomass to Liquid), produced from the feedstock listed in Part B of the Annex IX to the RED II directive through FT pathways.

Biofuels are produced from biomass. They also require some quantity of electricity, more for BtL than for HEFA. In this document, AtJ are not considered as, when used on lignocellulosic feedstocks, their output efficiency is limited.

- **PtL** (Power to Liquid) i.e. synthetic liquid fuels which may be produced in a transitory phase from recycled carbon, and which will ultimately use carbon directly issued from air capture (DAC).
- **e-BtL**, derived from the FT pathway, where hydrogen is injected after the biomass gasification phase in order to make it possible to reach the stoichiometric equilibrium of the Fischer-Tropsch reactions and to increase the quantity of biofuels produced. e-BTL are a trade-off between BtL and PtL.
- **Aviation Hydrogen**.

## Three scenarios to achieve partial or nearly complete decarbonisation with different amounts and types of feedstocks

This paper considers three scenarios with the aim to determine which quantities of SAF will be necessary until 2050 and the amount of feedstocks (biomass and electricity) that will be required to produce them.

These scenarios have been implemented in a model developed by ONERA (Office National d'Etudes et de Recherches Aérospatiales, the French national Aerospace lab)[1]. They are the following:

- **Scenario 1 (ReFuelEU)** is based on the ReFuelEU target of achieving 70% of SAF, with a minimum of 35% of synthetic aviation fuels, by 2050;
- **Scenario 2 (RefuelEU with e-BtL)** is based on the same target but it relies to a large extend on e-BtL, in order to contain the biomass requirements, assuming that biomass feedstocks will be limited in availability;
- **Scenario 3 (85% of SAF in 2050)** is based on a 85% target of SAF in 2050, assuming that such a target will be necessary to reach carbon neutrality of the aviation sector. Like scenario 2, it widely relies on the development of e-BtL.

These scenarios have been applied to the EU27 area. They take into account the expected evolution of the regional traffic on regional, short, medium and long range flights and all the measures that will contribute to the reduction of $CO_2$ emissions, such as:

- the renewal of current fleets with latest-generation aircraft (based on average life-length of aircraft of 20 years);
- from 2035, the launch of a new generation of aircraft that will reduce the emissions by 20 to 30%;
- the optimisation of operations (air traffic and airports operation);
- the emergence of $H_2$ aircraft from 2035/45;
- the incorporation of an increasing percentage of SAF.

1. *More information about the different assumptions used can be found at https://www.ecologie.gouv.fr/sites/default/files/Proposition%20de%20feuille%20de%20route%20d%C3%A9carbonation%20transport%20a%C3%A9rien.pdf*

# SCENARIO 1: ReFuelEU

Scenario 1 is consistent with ReFuelEU: 70% of SAFs in 2050 (of which 35% of BtL/ HEFA and 35% of PtL) – HEFA is supposed to rapidly reach a plateau of 2,5 Mt – BtL includes AtJ and Gasification+FT but AtJ is not supposed to develop significantly – e-BtL is taken as zero – In addition $H_2$ is supposed to cover 9,6% of energy needs (table 1 and figures 1 to 2).

Tab. 1: **Scenario 1 main hypothesis for 2050.**

| Scen 1 - 2050 | Includind $H_2$ | Jet fuel only |
|---|---|---|
| BtL & HEFA | 31,6% | 35,0% |
| e-BtL | - | - |
| PtL | 31,6% | 35,0% |
| Kero | 27,1% | 30,0% |
| Sub-total | **90,3%** | **100,0%** |
| Hydrogen | 9,6% | |
| Total | **100,0%** | |

Fig. 1: **Scenario 1 - Repartition between fuels (not including hydrogen).**

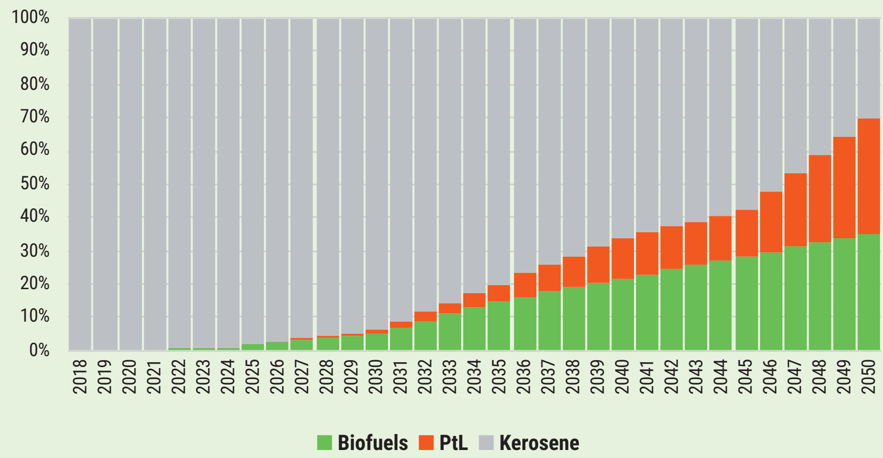



Fig. 2: **Scenario 1 - Repartition between fuels in 2050 (including hydrogen).**

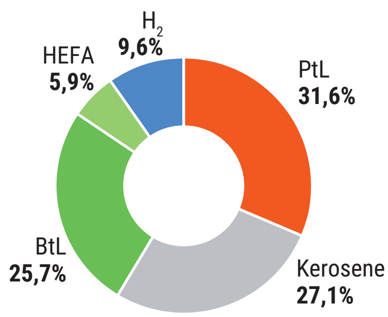
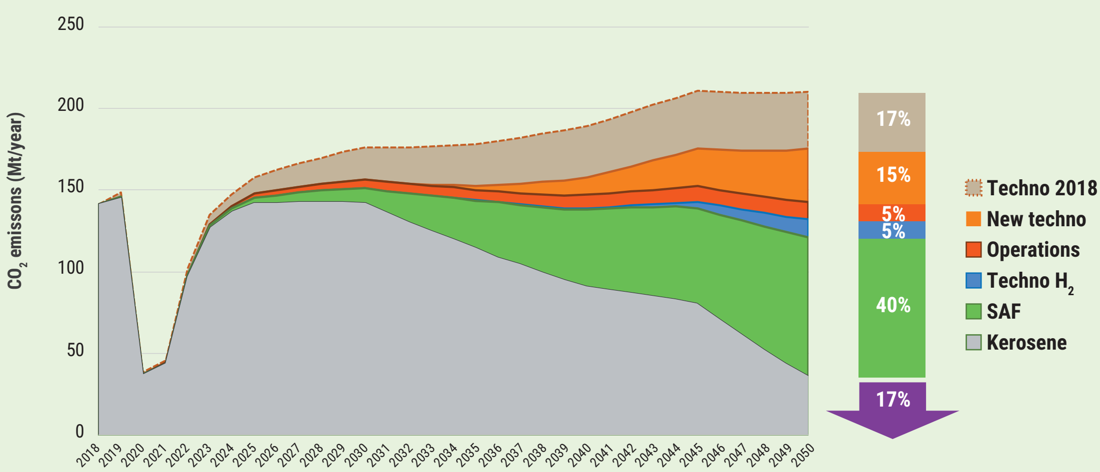



Fig. 3: **Evolution of $CO_2$ emissions of the aviation sector in scenario 1.**



Based on these assumptions, the aviation sector's $CO_2$ emissions shall evolve as shown on figure 3. According to these results, there would remain 17% of the emissions trend, as calculated with today's ratios, that would need to be offset through other measures in 2050.

Scenario 1 requires a fast growing quantity of biomass in the first decades. Then, due to the emergence of the PtL pathway, low-carbon electricity will take over (figure 4). The required quantities of biomass and electricity are summarised in table 5 for 2030, 2035, 2040 and 2050. In 2050, they amount respectively to 90,0 Mt (biomass) and to 570,1 TWh (electricity).

The 90 Mt figure is substantially higher than the evaluation proposed by the European Commission in its impact assessment for a blending mandate of 65% (62,5 Mt of solid biomass in 2050). However, it is not clear whether or not the assessment of the Commission includes the quantities of biomass associated with the co-products of the SAF production. If only the biomass associated with the SAF production is considered, the 90 Mt figure is brought down to 63,3 Mt which is very close to the evaluation of the Commission.

Upstream emissions associated with the production of SAFs also need to be taken into account. In particular, it is essential that electricity becomes low-carbon, that conversion efficiencies are increased and that all emissions related to the production and transport of SAFs are reduced (figure 5).

Fig. 4: **Feedstocks required in scenario 1 (biomass and electricity).**

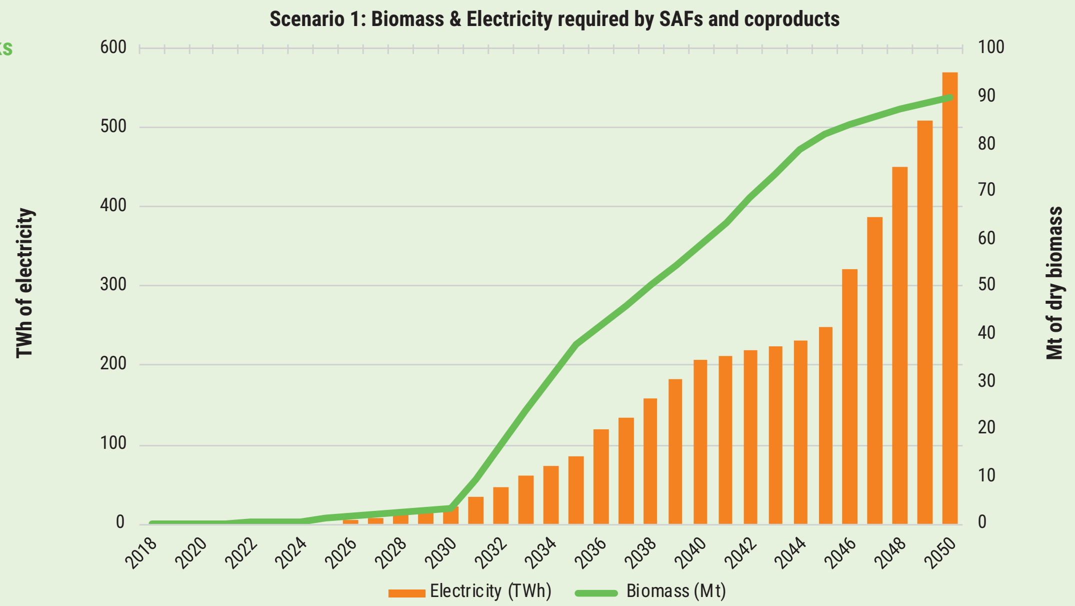
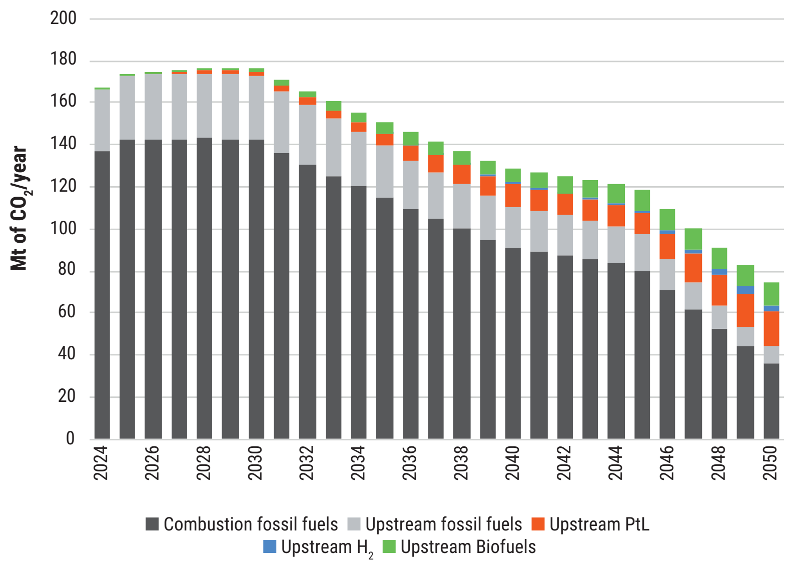



Fig. 5: **$CO_2$ emissions evolution in scenario 1 in lifecycle.**



## SCENARIO 2: ReFuelEU with e-BtL

Scenario 2 is based on the same decarbonisation target as scenario 1 (70% of SAF in 2050) but it relies more significantly on e-BtL in order to require less biomass feedstocks than scenario 1.

Data and main results related to scenario 2 are summarised in table 2 and figures 6 to 7.

In this scenario, the $CO_2$ emissions to be offset in 2050 remain very close to 16/17% of the emissions trend. However, the amount of dry biomass necessary in 2050 is brought down to 56,2 Mt while the low-carbon electricity required is brought up to 711 TWh, i.e. 21% of the today's annual electricity production of EU27.

Tab. 2: **Scenario 2 main hypothesis for 2050.**

| Scen 2 - 2050 | Includind $H_2$ | Jet fuel only |
|---|---|---|
| BtL & HEFA | 13,9% | 17,5% |
| e-BtL | 13,9% | 17,5% |
| PtL | 27,8% | 35,0% |
| Kero | 23,8% | 30,0% |
| Sub-total | **79,4%** | **100,0%** |
| Hydrogen | 20,7% | |
| Total | **100,0%** | |

Fig. 6: **Scenario 2 - Repartition between fuels (not including hydrogen).**

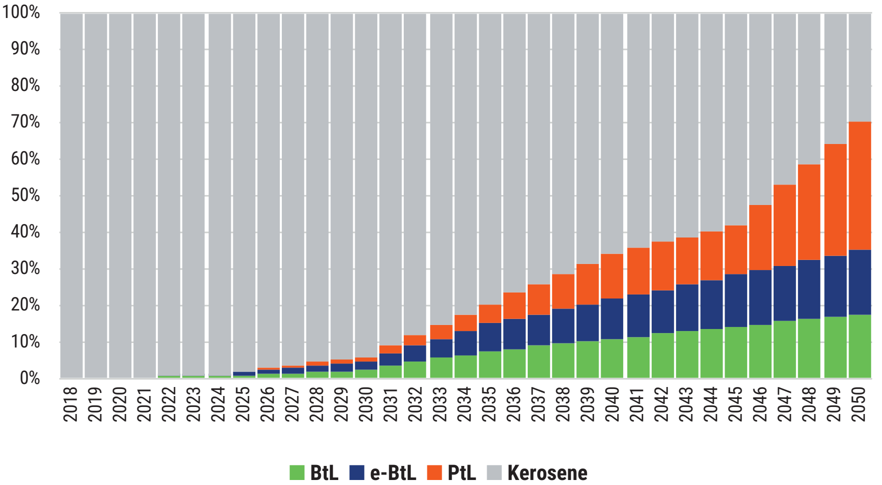
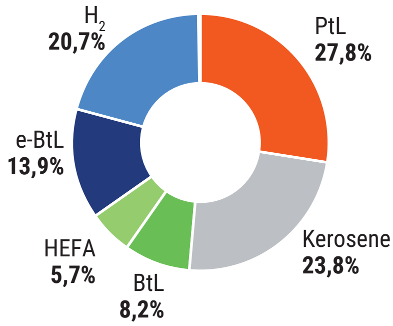



Fig. 7: **Scenario 2 - Repartition between fuels in 2050 (including hydrogen).**




## SCENARIO 3: 85% of SAF in 2050

Scenario 3 is based on the same decarbonisation scenario as scenario 2 but it aims at reaching a 85% of SAF in 2050. With the contribution of carbon sinks, this would make it possible to reach the carbon neutrality of the aviation sector.

Data and results related to scenario 3 are summarised in table 3 and figures 8 to 9.

In scenario 3, the $CO_2$ emissions that need to be offset through other measures or via carbon sinks in 2050, are brought down to 8% of emissions trend. But the quantity of dry feedstock that will be necessary in 2050 is brought up to 76,9 Mt and the amount of electricity required is to 804,1 TWh (i.e. 24 % of the today's annual electricity production of EU27).

Tab. 3: **Scenario 3 main hypothesis for 2050.**

| Scen 3 - 2050 | Includind $H_2$ | Jet fuel only |
|---|---|---|
| BtL & HEFA | 17,8% | 22,4% |
| e-BtL | 17,8% | 22,4% |
| PtL | 31,7% | 39,9% |
| Kero | 12,0% | 15,2% |
| Sub-total | **79,4%** | **100,0%** |
| Hydrogen | 20,7% | |
| Total | **100,0%** | |

Fig. 8: **Scenario 3 - Repartition between fuels (not including hydrogen).**

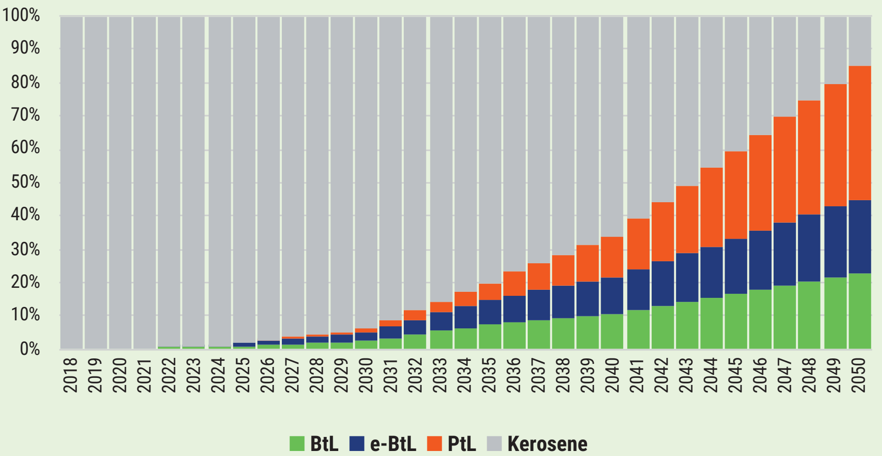
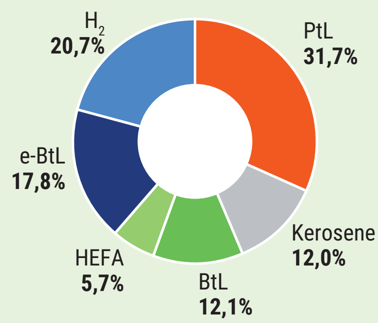



Fig.9: **Scenario 3 - Repartition between fuels in 2050 (including hydrogen).**



## Synthesis of the results

Table 4 summarises the quantities of biomass and electricity that will be required in each of the scenarios by 2030, 2035, 2040 and 2050.

Tab. 4: **Synthesis of the three scenarios. These data include the quantities directly associated with the production SAF but also the quantities related to co-products (naphta).**

| | Scenario 1 (ReFuelEU) | | Scenario 2 (ReFuelEU with e-BtL) | | Scenario 3 (SAF 85% in 2050) | |
|---|---|---|---|---|---|---|
| **Biomass** | 2030 | **3,2 Mt** | 2030 | **4,0 Mt** | 2030 | **4,0 Mt** |
| | 2035 | **37,8 Mt** | 2035 | **32,7 Mt** | 2035 | **32,7 Mt** |
| | 2040 | **58,8 Mt** | 2040 | **43,7 Mt** | 2040 | **43,7 Mt** |
| | 2050 | **90,0 Mt** | 2050 | **56,2 Mt** | 2050 | **76,9 Mt** |
| **Electricity** | 2030 | **21,4 TWh** | 2030 | **24,4 TWh** | 2030 | **24,4 TWh** |
| | 2035 | **85,8 TWh** | 2035 | **117,4 TWh** | 2035 | **117,4 TWh** |
| | 2040 | **206,4 TWh** | 2040 | **280,5 TWh** | 2040 | **280,5 TWh** |
| | 2050 | **570,1 TWh** | 2050 | **710,7 TWh** | 2050 | **804,1 TWh** |

## Will the resources be available?

All three scenarios require large amounts of biomass and electricity. How is it possible to make them available?

### Biomass

Assessing the availability of biomass feedstocks is extremely difficult because of their diversity. New energy crops may become available but aviation is competing with other sectors such as energy, road and maritime transport. The use of agri and forestry wastes is also disputed by some environmental actors.

Resources for HEFA will be limited in Europe (2.8/3.1 Mt). Consequently, according to the impact assessment of the European Commission, in scenario 1, SAF production will require about 11% of the EU's available potential of agricultural residues and wood waste, 3.0% of the available potential of forestry products and residues, and 9.4% of the available potential of energy crops[2]. According to the European Commission, these resources can be made available.

Our estimates are 50% higher, taking into account the biomass requested by the SAF co-products.

Based on several studies (Material Economics[3], The Royal Society[4], Académie des Technologies[5]), the European Commission's assumption appears optimistic, even if the inclusion of category 3 animals fats of provides some flexibility, within the limit of 3%.

In the study carried out by the Imperial College on behalf of the Concawe[6], results are more positive but they are considered by many specialists as over optimistic and the Imperial college acknowledges that "*Even if the potential is there, the supply chain would need to be developed to mobilise all these resources*". As a matter of fact, biomass resources will likely not increase and resources availability is not the only problem, as biomass also has to be collected in environmentally and economically acceptable conditions. **The quantities of biomass that can be collected in scenario 1 are most likely an absolute maximum and the European Commission recognises that the SAF development means "*higher competition between sectors of the economy for access to feedstock*".**

*2. Communication COM(2021) 561 final 14/072021 (page 41).*

*3. https://materialeconomics.com/latest-updates/eu-biomass-use*

*4. https://royalsociety.org/-/media/policy/projects/net-zero-aviation/net-zero-aviation-fuels-policy-briefing.pdf*

*5. https://www.academie-technologies.fr/wp-content/uploads/2023/03/Rapport-decarbonation-secteur-aerien-production-carburants-durables-AT-Mars-2023.pdf*

*6. https://www.concawe.eu/publication/sustainable-biomass-availability-in-the-eu-to-2050/*

**This leads to two recommendations:**

- **priority should be given to the aviation sector for the use of the biomass that is eligible for the production of SAF under the ReFuelEU regulation;**
- **the needs for biomass should be limited as much as possible by promoting scenarios associated with more limited biomass needs, such as scenario 2, which requires 38% less biomass in 2050 than scenario 1. Developing additional electricity resources appears to be a more realistic prospect than increasing the quantities of available biomass.**

### Electricity

The quantities of electricity needed in 2050 in scenarios 1 and 2 (570 TWh in scenario 1 and 710 TWh in scenario 2) represent respectively 17% and 21% of the current electricity production in Europe (3 371 TWh in 2018),

These quantities are significant, even when considering the possible improvements in process efficiency. Electricity will have to compensate for the limited resources of biomass.

In addition, the development of PtL, notably based on Direct Air Capture, will require large amounts of energy. Heat may come from the FT synthesis but the electricity – which will have to be low-carbon – will have to be produced.

In order to ensure that enough low carbon electricity is available, it is necessary to plan ahead the development of adequate means of production, likely a mix of renewable forms of energy and of new nuclear power plants.

Without such investment, Europe would have to massively import SAF from third countries, which may raise political and strategic questions as regards Europe's energy independence.

One possibility could be to produce a percentage of the hydrogen requested by steam methane reforming (SMR) associated with carbon capture and storage (CCS). This solution would reduce the investment in the electricity system but would result in maintaining some imports of gas. A study should be initiated on how to optimize the production and transport ecosystems of SAF, hydrogen and $CO_2$.

## Conclusions

Decarbonising aviation requires the uptake of SAFs which will play a key role in this transition. Most technologies are available, but they must be further improved in order for them to be more efficient and more price-competitive.

Biomass feedstocks is the main challenge as resources are limited, at least in Europe, and will remain so, and as their collection is a difficult process. In order to cover the needs of the aviation sector, it will be necessary that a significant proportion of the available biomass is reserved for aviation, which implies that air transport is given priority for its use over other sectors for which other decarbonation solutions are available, in particular heavy-duty vehicles which can be powered by electricity or hydrogen.

Electricity makes it possible to compensate for the limitation of biomass resources and direct capture of $CO_2$ in the air will have to be considered in order to have enough climate neutral carbon resources.

A trade-off between biomass and electricity will have to be found but every scenario will be associated with large electricity needs. For this reason, it is necessary to plan ahead the electricity infrastructure investments, as well as the investment related to the development of hydrogen and of CCUS, in order to make it possible to have the required resources available on time for the aviation's decarbonisation trajectory to follow its course.

### Acknowledgement

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