Overview of relevant laws and industry standards for the market ramp-up of sustainable aviation fuels

Contact us

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1 Introduction

With the Paris Climate Agreement of 2015, 195 signatory states agreed to reduce greenhouse gas (GHG) emissions in order to limit the rise in global temperatures [1]. The European Green Deal was followed by climate targets for the EU and the Inflation Reduction Act (IRA) was launched in the USA.

In the aviation sector, various programmes and measures to achieve CO_2 neutrality in air traffic have been implemented by global institutions based on the objectives of the Paris Agreement. At international level, the industry has set itself the goal of operating in a more climate-friendly manner with net-zero CO_2 emissions from 2050. In addition to innovative aircraft technologies, infrastructure optimisation and the use of offsetting measures, the aviation industry is focusing primarily on the use of Sustainable Aviation Fuels (SAF). The International Air Transport Association (IATA) sees the use of synthetic fuels as the largest element of its strategy to reduce emissions, with a share of 65 % [2].

In addition, the use of SAF enables the potential for further benefits through the reduction of so-called non-CO_2 effects, such as sulphur dioxide, soot emissions and ultra-fine particles (particulate matter). These non-CO_2 effects are responsible for about 2/3 of the climate-damaging impact of the aviation industry [3]. Reducing them would not only help the earth's climate in the long term, but would also improve air quality in the vicinity of airports, where particulate matter pollution in particular can lead to health risks for local residents.

However, the ecological advantage and technical feasibility are offset by the economic aspect that SAFs are still very expensive, as there are only a few producers. As a result, the available quantities and the corresponding utilisation rate of SAF are low. Depending on the source, SAF production volumes of between 0.5 million tonnes and 2 million tonnes are specified for 2023, which corresponds to a global fuel consumption of 0.2 % to 0.8 % [2, 4]. This share is to be further increased through corresponding quotas, which are defined in the ReFuel EU Aviation [5] (see chapter 2.3.1). At the same time, the fulfilment of the sustainability criteria of synthetic fuels must be guaranteed by strict framework conditions, e.g. with regard to the CO_2 source or the used hydrogen.

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If SAFs are to make their contribution to climate-friendly aviation and fulfil the defined quotas, the development, production and use of these fuels must be accelerated and politically supported through a targeted market ramp-up. This is where the **InnoFuels joint project** (duration 2023-2026) funded by the Federal Ministry for Digital and Economic Affairs and Transport (BMDV) comes in. It is intended to contribute to an accelerated market ramp-up of electricity-based fuels and advanced biofuels, so-called reFuels[1], by promoting the networking of players and activities, the further development of technologies and the presentation of the framework conditions in the field of synthetic fuels. The aim of the platform is to achieve comprehensive networking and an intensive exchange of existing expertise in order to develop comprehensive solutions. The InnoFuels project fulfils the interdisciplinary nature of this task through cooperative work in seven subject-specific innovation clusters (production, supply chain, aviation application, shipping application, road and rail application, sustainability and market & regulation), which work together in teams with experts from science, industry and politics to develop solutions for the focus areas and bring them together.

The **Innovation Cluster "Application in Aviation"** has set itself the goal of contributing to an accelerated market ramp-up of SAF. The activities of this focus area are led by DLR (German Aerospace Centre) and CENA Hessen (Competence Centre for Climate and Noise Protection in Aviation) and supported by Condor Flugdienst GmbH as an associated partner. The tasks of the field of application are to analyse and classify the obstacles to the market ramp-up of SAF and to develop options for action and research ideas against the background of these challenges. As first step this report gives an overview about the regulations, laws and industry standards forming the framework conditions for the market ramp-up of SAF at international, EU-wide and national level.

[1] The term "renewable energy fuels (reFuels)" covers all fuels that are produced on the basis of renewable energies. These include synthetically produced hydrocarbons based on green hydrogen and sustainable biofuels. [60]

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2 Overview of existing and planned relevant framework conditions

2.1 International framework conditions for the use of SAF

At an international level, the market ramp-up of SAF is largely characterised by the commitment of major aviation institutions. One of these is the International Civil Aviation Organisation (ICAO), a specialised agency of the United Nations, in which Germany is also involved as a member state in a global context. Its main task is to draw up and develop standardised regulations for the safety, regularity and efficiency of international air traffic [6]. With regard to the global development of sustainable fuels, the ICAO sees itself as a mediator to support states in their efforts to develop and deploy SAF [7].

Secondly, IATA, which represents the airline industry with 329 members in over 120 countries [8], is committed to harmonised air traffic regulations worldwide. There are currently ten German airlines among the IATA members.[2] In its SAF roadmap from 2015, the industry association defines its primary role as helping to commercialise and introduce SAF, implement policy recommendations, provide expert input to relevant working groups and remove barriers to the use of these fuels [9].

2.1.1 The ICAO global framework

In its **Vision 2050 for sustainable fuels**, the ICAO calls on its member states, the industry and other stakeholders to replace a significant proportion[3] of conventional aviation fuels with sustainable fuels by 2050. The aim is to significantly reduce CO_2 emissions from international civil aviation, while at the same time utilising all other possibilities for reduction measures [10]. The path towards this goal was further specified at the third ICAO Conference on Aviation and Alternative Fuels in November 2023 with the adoption of a new **ICAO global framework** for sustainable aviation fuels (SAF), low-carbon aviation fuels (LCAF) and other sustainable energies in aviation. The ICAO and its member states have

[2] IATA members from Germany are Condor, Discover Airlines, European Air Transport, Eurowings, German Airways, Hahnair, Lufthansa, Lufthansa Cargo, Lufthansa CityLine and TUIfly [8]

[3] This share was not quantified in more detail by the ICAO

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set themselves **the goal of reducing CO_2 emissions in international aviation by 5 % by 2030**. In addition to the common vision for the transition to sustainable energy, the key elements of the framework include harmonised regulatory principles, supporting implementation initiatives and improved access to funding for corresponding initiatives so that "no country is left behind" [11].

ICAO's activities are based on four approaches:

- The definition of SAF objectives and guidelines,
- Supporting its member states in the development of competences,
- The development of globally recognised environmental standards for SAF, e.g. within the framework of CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation)
- And the dissemination of information and best practice

The Long-Term Aspirational Goal: SAF's potential

In support of the Paris Agreement, in October 2022 the member states of the ICAO adopted a joint long-term goal, the **Long-Term Aspirational Goal (LTAG)** [12], of net zero CO_2 emissions by 2050 for international aviation. This goal is to be achieved through a combination of several measures to reduce emissions. In addition to the accelerated introduction of new and innovative aircraft technologies and more efficient flight operations, the increased production and use of sustainable fuels also play a key role. The LTAG report on which this goal is based, which presents three scenarios, shows that sustainable fuels[4] have the greatest potential to reduce CO_2 emissions from international aviation. Accordingly, CO_2 savings from sustainable fuels could reach up to 55 % by 2050. In addition, hydrogen and SAF based on atmospheric CO_2 could play a significant role by 2070, with CO_2 reductions from these fuels potentially reaching 88 %.

The LTAG does not assign specific obligations or commitments to individual states in the form of emission reduction targets. Instead, it recognises that each country's circumstances and capabilities (e.g. level of development, maturity of aviation markets or

[4] According to the ICAO's LTAG report, sustainable fuels comprise three categories: (1) Sustainable Aviation Fuels (SAF) based on biomass, waste and atmospheric CO_2, (2) Low Carbon Aviation Fuels (LCAF) based on petroleum and (3) non-drop-in fuels such as hydrogen and electricity. An LCAF is defined by the ICAO as a fossil-based fuel that fulfils the CORSIA sustainability criteria. [61]

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national priorities for aviation development) will determine each country's potential to contribute to the LTAG within its own national timeframe.

The ACT-SAF programme: supporting member states in building up expertise

To accelerate the availability and use of SAF, the ICAO programme "Assistance, Capacity-building and Training for Sustainable Aviation Fuels", ACT-SAF for short, was launched on 1 June 2022 [13]. The programme aims to provide tailored support to states at various stages of SAF development and implementation, facilitate partnerships and collaboration on SAF initiatives under the coordination of ICAO, and serve as a platform for knowledge sharing and mapping of all SAF initiatives worldwide. To date, 90 countries and 60 organisations have agreed to actively participate in the ACT-SAF programme. Germany has not yet approved the programme [14].

CORSIA: International system for offsetting and reducing CO_2

With the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the ICAO created a market-based climate compensation system in 2016. This involves offsetting the CO_2 emissions that cannot currently be avoided in aviation as an out-of-sector measure outside of the actual aviation sector. This is done by financing CO_2 reducing climate protection projects with project credits, known as offsets. The system will be introduced in three stages: A pilot phase ran from 2021 to 2023. A first phase with voluntary participation will follow from 2024 to 2026. In a second phase from 2026 to 2035, participation will finally become mandatory for all member states. To date, 88 countries (including 44 European countries, the USA, Canada and Japan), which together account for around 77 % of global air traffic, have already committed to voluntary participation from the outset. The airlines of all ICAO member states have been obliged to report their CO_2 emissions as part of CORSIA since 2019.

CORSIA applies to all civil, international flights that connect two participating countries. The emissions to be offset are calculated using a dynamic approach, which is initially designed as a sectoral approach and will gradually change to an individual approach from 2030. The sectoral calculation is based on the average global CO_2 growth rate, the percentage of which an airline must apply to its own CO_2 emissions. The growth of an airline is not considered. The individual approach, on the other hand, calculates the amount of

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compensation on the basis of the airline's own CO_2 emissions. By 2030, airlines that grow less globally will therefore pay more compensation than they cause in CO_2 emissions [15].

The CORSIA system also includes an option to reduce the offsetting obligations through the use of SAF and LCAF. The condition for such offsetting is the use of a CORSIA Eligible Fuel (CEF). In order for a fuel to become an eligible CEF, various criteria must be met. These are defined in the ICAO Environmental Report of 2019 [16]. For example, the Committee on Aviation Environmental Protection (CAEP) of the ICAO Council has developed standard values for life cycle emissions for CORSIA eligible aviation fuels produced from 16 different raw materials.[5] In addition, the production process must be carried out in accordance with a certified procedure of the organisation standardisation ASTM (see section 3.1.1). As a final criterion, the fuels must receive sustainability certification based on a certification process developed by the CAEP. In summary, the procedures and requirements for a CEF that can be considered within the framework of CORSIA are set out in the following five ICAO documents:

- CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes (SCS)
- CORSIA Approved Sustainability Certification Schemes
- CORSIA Sustainability Criteria for CORSIA Eligible Fuels
- CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels
- CORSIA Methodology for Calculating Actual Life Cycle Emissions Values

In accordance with its resolution A39-3 [17], the ICAO stipulates that CORSIA should be the market-based compensation measure for CO_2 emissions from international aviation. At European level, however, the European Emissions Trading Scheme (EU ETS) is also in force (see section 2.3.1). As part of its 4-pillar strategy to reduce emissions, IATA is also striving to use recognised compensation measures [18]. The association takes a critical view of regional measures, such as the EU ETS, as this could lead to distortions of competition in an international market and undermine a global measure such as CORSIA [19].

[5] The 16 calculated raw materials include agricultural residues, forestry residues, household waste, used cooking oil, tallow, maize oil, soya bean oil, rapeseed oil, palm oil, sugar cane, sugar beet, maize grains, poplars, reeds, switchgrass and palm fatty acid distillate (as at February 2019) [16]

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2.1.2 IATA's 4-pillar strategy

Sustainable aviation fuels are also a key pillar of IATA's strategy to reduce emissions. At the 77th IATA Annual General Meeting in 2021, the airlines made a commitment in the "Net zero carbon 2050 resolution" [18] to no longer produce any CO_2 emissions from 2050 in order to support the goals of the Paris Agreement. In addition, IATA made a further declaration of commitment in 2022 by agreeing to the ICAO's ambitious long-term "LTAG" target. Both institutions are therefore pursuing the same decarbonisation goals at a global level.

IATA sees the potential of SAF as a contribution to reducing emissions and achieving climate neutrality in 2050 at 65 % and therefore as the largest element in its 4-pillar strategy. Alongside this are the use of offsetting measures, including carbon capture and storage (CCS) technology (19 %), investment in new aircraft technologies (13 %) and improvements to infrastructure and operational efficiency (3 %).

In its SAF policy, IATA has formulated that it promotes harmonised guidelines across countries and industries, regardless of the technology and the raw material [20]. Measures to promote the commercial use of biofuel in aviation were already defined in its SAF roadmap [9] from 2015:

- Bringing together stakeholders in the field of alternative fuels
- Political support at national, regional (e.g. EU) and international (UN) level to create framework conditions for the commercialisation of SAF
- Removal of obstacles to the development of a competitive SAF market
- Promoting the use of SAF in accordance with robust sustainability criteria
- Raising public awareness of the industry's efforts in this area
- Taking a leading role in setting standards for drop-in SAF in the areas of technical certification and logistics and providing appropriate technical support
- Establishment of a platform for the exchange of knowledge, both between airlines and for external partners (e.g. airports)

2.2 Excursus: General conditions for SAF in the USA

The framework conditions for the use of SAF in the USA are significantly influenced by the Inflation Reduction Act (IRA) of 2022. The planned funding volume of 369 billion US dollars

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(USD) is to be channelled primarily into climate protection and forward-looking industries over a period of 10 years. The IRA aims to boost economic growth, promote climate and environmental protection and strengthen social justice. A core objective of the IRA is to reduce CO_2 emissions in the USA by around 40 % by 2030 compared to 2005, which should also be accompanied by a reduction in inflation [21].

In order to achieve the goals of the IRA, various support measures and bonus programmes are being implemented. For example, the IRA forms the financial basis for the Fueling Aviation's Sustainable Transition (FAST) programme, specifically defined by IRA Section 40007, which aims to accelerate the production and use of SAF and promote the development of low-emission aviation technologies. The focus is on supporting the global goal of achieving net-zero greenhouse gas emissions by 2050 and promoting innovation in the aviation industry. The FAST-SAF part of the programme includes an investment of USD 244.5 million for infrastructure projects for SAF production, transport, blending and storage. In addition, USD 46.5 million will be provided for the technology part (FAST-Tech), which supports the development and demonstration of new aviation technologies to improve fuel efficiency and reduce emissions. This programme complements existing initiatives such as the Aviation Sustainability Center (ASCENT)[6], the Commercial Aviation Alternative Fuels Initiative (CAAFI)[7] and the Continuous Lower Energy, Emissions, and Noise Program (CLEEN)[8] and aims to establish the US as a leader in sustainable aviation [22, 23].

Another important aspect regarding the use of SAF in the US is the SAF credit, which is administered by the Department of the Treasury and the Internal Revenue Service (IRS). This form of tax credit applies to the sale of qualified sustainable aviation fuel blends in 2023 and 2024 and amounts to USD 1.25 per gallon[9]. In order for a fuel blend to be recognised as qualified, a minimum 50 % reduction in life cycle greenhouse gas emissions must be demonstrated. The emission reduction percentage is determined using either the

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[6] ASCENT is working on science-based solutions to reduce the environmental impact of the aviation industry and produce sustainable aviation fuels on a commercial scale. [56]

[7] CAAFI aims to develop and utilise alternative aviation fuels in order to improve the energy security and environmental compatibility of aviation. [57]

[8] The aim of CLEEN is to drive forward the development of aircraft and engine technologies in order to reduce noise, emissions and fuel consumption in aviation and thus improve environmental performance. [58]

[9] US gallon conversion: 1 gal = 3.785 litres

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CORSIA method (see chapter 2.1.1) or a similar method that fulfils the specific requirements of the Clean Air Act (CAA) [24].

The Renewable Fuel Standard 2 (RFS2) of the US Congress is the central regulatory instrument for renewable fuels in the USA. Similar to the Renewable Energy Directive (RED) in the EU[10], it defines the sustainability standards for renewable fuels as well as binding specifications for the blending of these fuels. Although the RFS2 is primarily aimed at road transport, its impact may also extend to the aviation sector. The RFS2 annual targets are expressed as a percentage by volume and are allocated proportionally among US-based refiners, blenders and importers to determine their target volume commitments for renewable fuels. Renewable Identification Numbers (RINs) are used to facilitate compliance with the RFS2 requirements. These RINs are tradable certificates that serve as labelling for the origin and use of renewable fuels. They are issued per gallon. If a fuel fulfils the correct RFS requirements, manufacturers and importers of SAF can also generate corresponding RINs. A company that uses SAF in accordance with the RFS2 needs a corresponding number of RINs to fulfil its obligations. If the company uses more SAF than required by law, it can in turn sell surplus RINs to other companies that cannot fulfil their obligations [9, 25].

2.3 Framework conditions at EU level

2.3.1 The European Green Deal

The European Green Deal [26] sets the target of achieving climate neutrality in the EU by 2050. This target requires a 55 % reduction in greenhouse gas emissions by 2030 compared to 1990 levels as part of the EU's "Fit for 55" package. This requires action at EU level to provide the right incentives for Member States to accelerate the transition from the current energy system, which is still largely based on fossil fuels, to a more energy-efficient energy system based on renewable energy sources. The EU member states have jointly adopted several aviation and climate-related directives and regulations as part of the European Green Deal.

[10] A comparison of the similarities and differences between the RFS2 and RED systems is shown in the IATA SAF Roadmap 2015 [9]

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The ReFuelEU Aviation Regulation

Against the backdrop of the Fit for 55 package, air transport is also called upon to make mobility more climate-friendly. This also includes to promote the use of SAF in air transport. This is ensured by the ReFuelEU Aviation Regulation [27] which defines, among other things, which aviation fuels are permitted to fulfil the quotas. In this context, it refers to the sustainability criteria of the Renewable Energy Directive (RED). It also specifies the SAF blending quotas that result from the regulation for distributors and the penalties for non-compliance [5].

The provisions of ReFuelEU Aviation aim to increase the use of sustainable aviation fuels in air transport. The defined SAF and Power-to-Liquid (PtL) quotas in Section 4 of ReFuelEU Aviation ensure a minimum quantity of SAF in aviation and provide for an increasing blending obligation from 2025 at all EU airports, which will be gradually increased until 2050. The minimum share of sustainable aviation fuels for airlines and airports in the Union[11] for 2025 provides for a blending obligation of 2 % SAF by 2028, rising to 6 % by 2030 and 70 % by 2050. During a transitional period until 2034, a weighted average will be applied throughout the EU (ReFuelEU Aviation § 15). If the quotas are not met, the member states are obliged to levy penalties (ReFuelEU Aviation § 12). A distinction is made between aircraft operators, airport managing bodies and aviation fuel suppliers [28, 29]:

- **Aircraft operators** are obliged to cover at least 90 % of their fuel requirements at EU airports (ReFuelEU Aviation § 5). If they fail to do so, the fine will be at least twice the amount calculated by multiplying the annual average price of fuel per tonne by the total annual quantity not used. Currently, the minimum amount for fines would correspond to around 2000 €/tonne.
- According to Section 6 of ReFuelEU Aviation, **managing bodies of EU airports** are obliged to provide access to SAF. If they do not fulfil this obligation, they must pay penalties. However, these are not defined in ReFuelEU Aviation, but are imposed by the member states.

[11] A "Union airport" is defined "within the meaning of Article 2(1) of Directive 2009/12/EC of the European Parliament and of the Council" as an airport that carried more than 800,000 passengers or more than 100,000 tonnes of cargo in the previous reporting period and that is not located in an outermost region listed in Article 349 TFEU" (ReFuel EU Article 3(1)).

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- According to Section 4 of ReFuelEU Aviation, **aviation fuel suppliers** must ensure that fuel with the prescribed minimum proportion of SAF is available. If they fail to do so, the fine is at least twice the amount calculated by multiplying the difference between the annual average price of synthetic and conventional aviation fuel per tonne by the amount of fuel that does not meet the minimum requirements. Currently, the minimum amount for penalty payments would correspond to around 3000 €/tonne. The shortfall must also be made up retrospectively in the following year or reporting period, particularly with regard to renewable fuels of non-biological origin (RFNBO).

The minimum penalties currently assumed are based on the market prices of biofuels, as there is currently no market price for PtL fuels.

Article 3 of ReFuelEU Aviation defines which aviation fuels can be used to achieve the minimum shares of SAF quotas. The scope of application includes certified biofuels, which may not, however, be produced on the basis of food and animal feed, and RFNBOs that fulfil the sustainability and emission reduction criteria of the RED Renewable Energy Directive. It should be noted that "recycled carbonaceous aviation fuels", "low-carbon aviation fuels" and "low-carbon hydrogen" may also be used to fulfil the quota, but these do not fulfil the sustainability criteria of the RED.

Renewable Energy Directive II & III and the Delegated Acts

By updating the Renewable Energy Directive (RED) from RED II to RED III, the binding Union target for the overall share of energy from renewable sources (renewable energies, RE) in the Union's gross final energy consumption for 2030 is being redesigned, as is the financial support for the use of electricity from renewable sources, use in the heating and cooling sector and in the transport sector.

The envisaged share of RE in all sectors, measured in terms of the Union's gross final energy consumption in 2030, increases from 32 % (RED II) to 45 % (RED III). The target RE share in the transport sector by 2030 increases from 14 % (RED II) to 29 % (RED III), of which 1 % is to be achieved through RFNBO. Alternatively, the sector targets in the transport sector can also be achieved via a GHG reduction of 14.5 % (RED III).

All EU member states are obliged to transpose the requirements of RED II and RED III into national law. In addition to the binding renewable energy directives for the various sectors,

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such as transport, in which aviation must contribute, the overarching targets also contain the sustainability criteria for renewable fuels and the greenhouse gas savings for biofuels, bioliquids and biomass fuels. The methodological concretisation of the production of renewable fuels takes place in the delegated acts of RED II, in which the requirements for SAF production are specified.

The delegated acts anchored in RED II concretise the regulatory framework for SAF production. In particular, Article 29a(1) of the RED defines which fuels can be considered sustainable. Accordingly, a fuel is sustainable if the greenhouse gas savings from the use of SAF and recycled carbon fuels (RCF) are at least 70 % compared to the fossil comparative value (94 g CO_2eq/MJ). Delegated Act (EU) 2023/1185 stipulates that these regulations also apply to RCF. The delegated act also defines the permitted CO_2 sources for PtL production. On the one hand, CO_2 can be obtained from point sources, but it should be noted that this may only be used until 2041. On the other hand, CO_2 can be obtained directly from the atmosphere, from biogas plants or other biogenic sources, as well as from natural sources where CO_2 was previously released directly into the atmosphere.

Delegated Act (EU) 2023/1184 also defines the various options for fulfilling the requirements for renewable electricity for PtL production. The options include direct procurement, a 90 % share of RES in the national grid or a power purchase agreement that fulfils the requirements for additionality as well as temporal and geographical correlation.

In addition, the RED defines the sustainability criteria for SAF and PtL with which the targets defined in the RED can be achieved and thus shows which fuels may be counted towards achieving the targets. According to the RED, biofuels[12], synthetic aviation fuels[13] and recycled carbon-containing fuels[14] fulfil the sustainability criteria for SAF and are therefore defined as sustainable aviation fuels according to the RED.

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[12] Biofuels are defined as liquid transport fuels produced from biomass (Art. 2 (33) RED) and from certain feedstocks listed in Part B of Annex IX RED. Advanced biofuels are biofuels that are produced from the raw materials listed in Part A of Annex IX (Art. 2 (34) RED).

[13] In the case of RFNBOs, synthetic aviation fuels are renewable fuels of non-biological origin (Art. 2 (36) RED).

[14] RCFs are defined as liquid or gaseous fuels that are not suitable for recycling in accordance with Article 4 of Directive 2008/98/EC or are produced from process and waste gases of non-renewable origin that arise as an unavoidable and unintended consequence of the production process in industrial installations (Art. 2 (35) RED).

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The European Emissions Trading Scheme (EU ETS)

The European Emissions Trading Scheme (EU ETS) is the EU's central climate protection instrument with the aim of reducing greenhouse gas emissions in the energy sector and energy-intensive industry [31]. It was established in 2005 to implement the international climate protection agreement of Kyoto and works according to the "cap-and-trade" principle (Directive 2003/87/EC). Since 2012, aviation has also been part of the EU ETS (Directive 2008/101/EC) and applies to all flights that take off or land within the European Economic Area (EEA). The previously low CO_2 pricing of air traffic was made significantly more ambitious by the reform of the EU ETS as part of the Fit for 55 package (Directive (EU) 2023/958). The reduction target for 2030 was tightened from 43 % to 62 % compared to 2005 and now also includes aviation and shipping. This is to be achieved by increasing the linear reduction factor[15] (LRF) from the current 2.2 % to 4.3 % from 2024 and to 4.4 % from 2028 (Art. 9 EU ETS). In addition, the cap is to be reduced by 90 million allowances in 2024 and by 27 million allowances in 2026. The rapid expiry of free allocation by the end of 2025 will be accompanied by the subsequent introduction of free allocation of a maximum of 20 million emission allowances for the use of sustainable fuels (so-called SAF allowances). These are intended to compensate airlines for the additional costs caused by the mandatory SAF blending quota (ReFuelEU Aviation) [32].

In addition, there will be a reporting obligation for non-CO_2 effects as part of the EU ETS from 2025. This will initially be included in the EU ETS via the monitoring, reporting and verification (MRV) of the non-CO_2 effects of aviation, and later probably also with a levy obligation. By the end of 2027, the European Commission will present a report – probably including a legislative proposal – that integrates non-CO_2 effects into the levy obligation. CORSIA will also be implemented for flights to and from third countries and between third countries in the EU ETS in the EEA [32].

[15] The available quantity of emission allowances in the EU ETS is limited by a cap in order to achieve the reduction target of the EU ETS. The progression of the cap is determined by a linear reduction factor, which reduces the cap by a certain amount of allowances each year. [59]

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2.3.2 EU taxonomy

The EU taxonomy [33] defines sectors and economic activities that are particularly relevant with regard to the transformation to a climate-neutral economy and uses criteria to determine which economic activities are to be categorised as environmentally sustainable. It thus determines the degree of environmental sustainability of an investment. It supports the objective of the European Green Deal by focussing on the reorientation of capital flows towards sustainable investments, the establishment of sustainability as a component of risk management and the promotion of long-term investments and long-term economic activity. For the sustainability assessment, the taxonomy defines six climate targets, the achievement of which should support taxonomy-compliant investments. The "do no significant harm" principle applies, according to which each activity must contribute to at least one of the defined environmental goals and must not significantly harm any other environmental goal. The six defined climate targets are

1. Climate protection
2. Adaptation to climate change
3. Sustainable use and protection of water resources
4. Transformation to a circular economy
5. Avoidance of soiling
6. Protection of ecosystems and biodiversity [34]

The Taxonomy Regulation (EU) 2020/852 provides the regulatory framework of the EU taxonomy for the general classification of "sustainable" economic activities. The EU Taxonomy Regulation thus forms the legal basis for the sustainability classification and enables greater market transparency for sustainable economic activities. This enables the integration of further economic activities into the EU taxonomy.

Based on the regulatory framework of the Regulation, various delegated acts shape the design for its application and implementation. For example, the Climate Delegated Act (Delegated Act (EU)2021/2139) defines the technical assessment criteria for the economic sectors and environmental targets, while the Disclosures Delegated Act (Delegated Act 2021/2178) formulates reporting requirements. Both delegated acts were updated in 2023 (Delegated Regulation (EU) 2023/2486 and Delegated Regulation (EU) 2023/2486). The controversial Complementary Climate Delegated Act (Delegated Act (EU) 2022/1214) included nuclear power and natural gas in the EU taxonomy in 2022.

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The transparent classification of relevant economic activities as sustainable is also essential for the aviation sector in order to manage sustainable investments sensibly. With a new package of measures, the EU Commission expanded the EU taxonomy in June 2023 to include additional economic activities, including in the transport sector. Under certain conditions, this also includes air transport operations [35].

2.4 National framework conditions

The GHG reduction targets are set at national level by the federal Climate Protection Act. This provides for a gradual reduction in GHG emissions of at least 65 % by 2030 and at least 88 % by 2040 compared to 1990 levels. Net GHG neutrality is to be achieved by 2045 and negative GHG emissions after 2050 [36].

In addition to the comprehensive regulatory instruments of the EU, a number of other legislative and strategic elements apply in Germany. The transposition of RED II into national law is set out in the **Federal Immission Control Act** (BImSchG) [37]. A PtL quota is anchored here for air traffic, which defines a blending obligation of 0.5 % by 2026, 1 % by 2028 and 2 % by 2030 (Section 37a (4a) BImSchG). Those obliged to implement this quota are distributors of aviation turbine fuels. If the national PtL quota is not met, a penalty must be paid based on the energy content of the calculated shortfall in the fuel. The estimated 70 euros per gigajoule (Section 37c (2) BImSchG) corresponds to a levy of around 3,000 €/tonne of PtL fuel not refuelled. At present, the penalty would therefore be at the lower end of the current production costs. Studies from 2023 and 2024 show that PtL costs in the range of just under 3,000 €/tonne to 4,400 €/tonne can currently be expected. Costs are not expected to fall until 2030, although due to the wide range of forecast production costs, it is to be expected that it will take well beyond 2030 for PtL costs to fall significantly below the penalty amount of 3,000 €/tonne [38, 39, 40].

Alternative fuels in the current government[16] programme

[16] Note: This translation refers to the "current government" as it was at the time of the original publication (2023). At the time of this translation (2025) the German government has changed.

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The **coalition agreement** [41] of 2021 between the governing parties (SPD, the Greens, and FDP) formulates the following goals with regard to alternative aviation fuels:

- Germany is to become a pioneer in CO_2 neutral flying.
- Pending a European decision on the introduction of a kerosene tax based on the energy content, the German government will advocate the introduction of a Europe-wide aviation tax, as is levied in Germany.
- Flight tickets should not be sold at a price below the taxes, surcharges, fees and charges.
- Revenues from the aviation tax are to be used to promote the production and use of CO_2 neutral, electricity-based aviation fuels as well as for research, development and fleet modernisation in aviation.
- The German government supports ambitious quotas for PtL in aviation and shipping in order to incentivise a market ramp-up.

However, these objectives must be considered against the backdrop of recent developments. In November 2023, for example, a ruling by the Federal Constitutional Court removed 60 billion euros from the reserves of the Climate and Transformation Fund (KTF) [42]. This led to corresponding savings in the federal budget and thus the cancellation of funding measures.

With the second Budget Financing Act, which was approved by the Federal Council on 22 March 2024 [43], the German government has initiated measures in connection with the agreement on the 2024 federal budget. This also increased the applicable rates of **air traffic tax** (also known as ticket tax, as it is levied on commercial passenger flights) with effect from 1 May 2024 (see Table 1). The programme expenditure of the Climate and Transformation Fund was reduced by 12.7 billion euros. At the same time, the "Climate-neutral flying" programme is to remain in the Climate and Transformation Fund.

	New, from 1 May 2024	Old, until 30 April 2024
Distance class I (Europe)	15.53 €	12.48 €
Distance class II (medium distance, e.g. North Africa or Middle East)	39.24 €	31.61 €

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Distance class III (long distance, including the American continent)	70.83 €	56.91 €

Table 1: Change in air traffic tax as of 1 May 2024 [44]

National biomass strategy

The coalition agreement also includes the creation of a **National Biomass Strategy** (NABIS) [45]. The Federal Ministry of Economic Affairs and Climate Protection (BMWK), the Federal Ministry of Food and Agriculture (BMEL) and the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) have already published a key issues paper for the creation of such a strategy in 2022. In view of the imbalance between the high and rapidly growing demand for plant and animal raw materials and the limited availability of biogenic waste and residual materials, the NABIS key issues paper sets out the following guiding principles for the utilisation of biomass:

- Principle of a utilisation hierarchy considering the possibilities of multiple and cascading uses to exploit the potential of the circular economy
- Prioritisation of material use; carbon should be sequestered for as long as possible
- Priority for multiple use
- Prioritising the use of biomass and biogenic waste materials

The National Biomass Strategy aims to develop a mix of instruments with a practical steering effect that ensures sustainable, climate-friendly and resource-efficient biomass production and utilisation. This should contribute to the development of reliable framework conditions for the policies of the federal states and for investments by industry. Existing disincentives and regulations for biomass production and utilisation are to be identified and adapted or further developed through suitable measures.

As a basis for the measures to be developed, the currently available sustainable biomass potential, the various areas of application and the current political framework conditions should be analysed. The measures to be formulated should themselves be based on the defined guiding principles and be divided into

(I) the consistent adaptation of existing policy instruments (e.g. funding programmes, regulatory law, reduction of subsidies harmful to the climate and biodiversity) to the aforementioned guiding principles and

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(II) the introduction of new measures to steer biomass flows (e.g. regulatory law or new economic incentive instruments).

Although the adoption and publication of the National Biomass Strategy was planned for 2023, it is currently only available as a draft version from the stakeholder participation process. The prioritised use of biogenic CO_2 for PtX production (Power-to-X) over CO_2 storage was still envisaged in the first draft versions. However, this measure was deleted again in the latest draft version.

National hydrogen strategy

The **National Hydrogen Strategy** (NWS) [46] published in 2020 was supplemented by an update [47] in 2023. While the NWS 2020 remains valid in principle, the national hydrogen production target for 2030 was doubled to 10 gigawatts (GW). The strategy assumes that national hydrogen demand will be 95-130 terawatt hours (TWh) by 2030 and will rise sharply thereafter. In addition, the current demand of 55 TWh of grey hydrogen[17] must be successively produced sustainably. The import quota is estimated at 50-70 % (45-90 TWh). Where necessary in the market ramp-up phase, low-carbon blue, turquoise and orange hydrogen[18] should be promoted alongside the use of green hydrogen – considering ambitious GHG limits, including upstream chain emissions and the maintenance of the legal goal of climate neutrality.

The National Hydrogen Strategy envisages the use of PtL fuels primarily in aviation and shipping. For climate-neutral aviation for short and medium-haul flights, support for the development of an initial refuelling infrastructure for liquid hydrogen is to be examined, depending on the availability of suitable aircraft.

Roadmap for PtL fuels

[17] Grey hydrogen is usually produced from fossil natural gas. It therefore generates CO_2 emissions and is not climate-friendly. [62]

[18] Green hydrogen is CO_2 neutral as it is produced by electrolysis of water using renewable energy sources. Orange hydrogen, which is produced from waste and residual materials, is also considered CO_2-free. Blue hydrogen is grey hydrogen, in the production of which CO_2 is partially captured and stored using CCS. Turquoise hydrogen is produced via the thermal decomposition of methane, resulting in solid carbon that does not escape into the atmosphere. [62]

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For the sake of completeness, the German government's **PtL roadmap** should also be mentioned in the context of the national framework conditions. The joint roadmap for the market ramp-up of electricity-based fuels from renewable energy sources was published in 2021 by the BMU (now BMUV, Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection), BMVI (now BMDV, Federal Ministry for Digital and Transport Affairs), BMWi (now BMWK, Federal Ministry of Economics and Climate Protection), BMZ (Federal Ministry for Economic Cooperation and Development) and the Federal Association of the German Aviation Industry (BDL). The aim of the roadmap is to significantly develop and expand the production of PtL kerosene generated from renewable electricity in Germany.

The aim is to bring air traffic more in line with national and international climate protection targets. Synthetic, sustainably produced fuels based on renewable energies are to contribute to CO_2 neutral flying by gradually replacing fossil kerosene with electricity-based kerosene (PtL). In addition, Germany wants to establish and expand its technological leadership in the production and use of PtL kerosene. The target defined is to have at least 200,000 tonnes of PtL kerosene available in German aviation by 2030. Some of the activities planned to achieve the PtL roadmap targets have been overtaken by the finalisation of various legislative elements as part of the European Green Deal, e.g. the sustainability criteria, binding sales targets in the form of blending quotas, etc.

3 Fuel and technology requirements: Overview of existing and planned relevant industry standards

3.1 Standards and conformity with norms at international level

Aviation takes place globally and its safety is a top priority. International standards must therefore be set for the production and use of fuels. ASTM International, an international standardisation organisation based in the USA, is particularly important for certification and approval. If fuels and production routes are certified and approved by ASTM, they are internationally recognised and have worldwide validity. For use in Germany, this means that the ASTM-certified fuel can be used without having to be included in the German law as mentioned in the Federal Immission Control Ordinance (BImSchV) [49].

After the first test flight with an SAF blend took place in February 2008 by the airline Virgin Atlantic, this led to many further test flights by numerous airlines with different aircraft and engine types as well as fuel blends from various raw materials. At the same time, technical certification of alternative fuels was carried out under the direction of ASTM and with the strong support of the Commercial Aviation Alternative Fuels Initiative (CAAFI) and the US Air Force, which led to the approval of the first SAF in 2009, a fuel produced using the Fischer-Tropsch process that can be used for commercial aviation with a blending percentage of 50 % [50].

3.1.1 ASTM standards

ASTM specification D1655 for Jet A and Jet A-1

In commercial aviation, an aviation fuel may only be used if it fulfils all the requirements of ASTM specification D1655, which has been in existence since 1959. This defines the requirements for the composition and properties of the classic, crude oil-based fuels Jet A and Jet A-1. The relevant fuel properties include volatility, viscosity, combustion and corrosion properties as well as thermal stability. Limit values for impurities and a list of authorised additives are also provided [50].

Process standard according to ASTM D4054 for new synthetic fuels

In order to standardise the evaluation of new synthetic aviation fuels (SAF) and fuel additives, the ASTM Subcommittee for Synthetic Aviation Turbine Fuels has developed the process standard D4054. This defines the procedure for the approval and certification of new fuels, in which aircraft and engine manufacturers, among others, are involved. In addition to determining the composition and fuel properties, the test procedures include performance tests such as endurance tests in aircraft engines. All new fuels must undergo this certification process. If this process standard is successfully completed, the production path and the fuel are included in the annex of ASTM standard D7566 [50].

Fuel certification according to ASTM D7566

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ASTM standard D7566 is the only global specification for jet fuel containing synthetic hydrocarbons. It defines the composition (including permissible additives), properties and also the production route for the synthetic components. It was published in 2009 by the ASTM Subcommittee on Synthetic Aviation Turbine Fuels and ensures the compatibility of approved fuels with all aircraft, regardless of type, age, engine, etc. ASTM D7566 is applied to synthetic blend components that have successfully passed the ASTM D4054 certification process. ASTM D7566 has been incorporated into the UK's Defence Standard 91-091 (DEF STAN 91-091) and is also the standard by which aviation fuels are purchased in Europe and Asia.

The standard currently contains eight annexes. Each annex describes an approved method for the production of a synthetic blend component that may be added to conventional jet fuel (Jet A or Jet A-1) and thus corresponds to a fuel that fulfils the requirements of the standard specification according to ASTM D1655 in a mixture of up to 50 % with Jet A / Jet A-1. Each annex contains the definition of the permitted raw materials, the manufacturing process, the properties of the blend components and the blending criteria or proportions. Accordingly, fuels that fulfil ASTM D7566 are to be regarded as classic Jet A-1 in accordance with ASTM D1655 [50].

3.1.2 Status of the SAF authorisation

The most promising processes for SAF production to date are the HEFA process and the Alcohol-to-Jet (AtJ) route. The HEFA process is based on the hydrogenation of natural esters and fatty acids, whereby mainly used edible fats and oils are utilised in the application. For the AtJ process, short-chain alcohols with 2 to 5 carbon atoms are converted to SAF in a multi-stage process[19]. The alcohols can be obtained in biotechnological processes or produced from carbohydrates and lignocellulose as well as synthesis gas or industrial waste gases. Since the end of 2023, two different AtJ production processes have been approved, which differ in terms of the composition of the product.

[19] This includes the dehydration of the alcohol molecules, oligomerisation and subsequent hydrogenation

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With the Methanol-to-Jet (MtJ) process, a third process variant could be added, whereby no biogenic material is used as a feedstock, but this is attributed to the PtL processes.[20]

What the HEFA and AtJ processes have in common is that they are biogenic processes, i.e. they are based on the use of biomass. As the use of biomass will sooner or later limit SAF production due to its finite availability, the production of SAF via the PtL process is of immense importance for the future supply of sufficient quantities of SAF. For example, the aviation organisation ATAG (Air Transport Action Group) expects that the proportion of PtL kerosene will increase more and more from 2030 and will be able to cover around half of SAF production in 2050 [51]. The core of PtL technology is the Fischer-Tropsch (FT) process, which, similar to the HEFA process, is already known on an industrial scale. The challenge here currently lies in the coupling of all the necessary process steps, the generation of sufficient quantities of green hydrogen from electrolysis (which is mainly reflected in the costs) and the efficient provision of the synthesis gas, which serves as a reactant stream for the FT reactor [49].

An overview of all SAFs approved by the ASTM (including their manufacturing processes) is shown in Table 2. It should be noted that each manufacturing process must be considered against the background of existing international and national regulations on sustainability (e.g. RED II etc.).

From the admixture component to 100 % SAF

The overview of the manufacturing processes in Table 2 also shows that SAF has to be blended with Jet A-1 (or Jet A) in order to be used as a fuel. The maximum blending percentage of SAF permitted by ASTM D7566 is currently 50 %. If a fuel approved according to ASTM D7566 is mixed with Jet A-1 / Jet A, this mixture is to be regarded as a pure fuel according to ASTM D1655 and used [50]. The end result is therefore always the same product, regardless of which production path was followed in accordance with D7566.

There is currently no SAF in the appendix to ASTM D7566 that can be used 100 %. The corresponding specification would have to be adapted for authorisation. At this point, a distinction must also be made between SAF with and without aromatics. Aromatics are a

[20] Power-to-Liquid

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group of substances that promote the formation of soot particles during combustion. Most manufacturing processes result in products that are predominantly paraffinic, i.e. contain no aromatics and are therefore characterised by a significant reduction in soot emissions. A minimum aromatics content of 8 % by volume is currently still a requirement for SAF in ASTM D7566, which makes the blending of purely paraffinic SAF with Jet A-1 unavoidable. The main argument for this is still the swelling behaviour of seals on contact with a fuel containing aromatics. However, it has been proven that modern aircraft can also be operated with an aromatic-free SAF. For the use of pure SAF, even in older aircraft, there is a lack of long-term tests and corresponding experience as to whether critical components such as seals or valves should be replaced and, if necessary, after what period of operation. However, these are also components that are routinely inspected during regular maintenance intervals and can replaced if necessary [38].

Although FT-SKA (Synthesized Kerosene with Aromatics) and AtJ-SKA (see Table 2) are already available as synthetic fuels that also contain synthetic aromatics, they are not approved for use as 100 % drop-in fuels, but must also be blended 50 % with Jet A-1. The reduction in soot particle emissions when using a 100 % drop-in fuel with aromatics would be less pronounced than with a 100 % synthetic fuel without aromatics, but similar or even better (depending on the proportion and type of aromatics) than with a 50 % blend [38].

The specification of AtJ-SKA with Annex 8 of ASTM D7566 approved in 2023 is seen as a major step towards certification of 100 % SAF. This fuel is obtained from the Alcohol-to-Jet process and is the first purely biogenic synthetic kerosene that contains aromatics (previously, coal and natural gas were mainly used for the production of FT-SKA, which is why it cannot be counted as an SAF here). The process was submitted by Swedish Biofuels and also includes the production of aromatics. According to the manufacturer, the proportion of aromatics can be varied flexibly so that AtJ-SKA does not differ from fossil kerosene in terms of its composition and properties [52].

There are numerous efforts to produce 100 % synthetic fuels that no longer need to be blended. A lot of work has been done in the last two years to demonstrate 100 % synthetic fuels and a D4054 method has been developed to make this possible. CAAFI estimates that it will be possible to adopt an amendment to the D7566 specification in the short term. [50]

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ASTM reference	Conversion process	Abbreviation	Possible raw materials	Max. Mixing ratio
ASTM D7566 Annex A1	Fischer-Tropsch hydroprocessed synthesised paraffinic kerosene	FT	Coal, natural gas, biomass	50 %
ASTM D7566 Annex A2	Synthesised paraffinic kerosene from hydroprocessed esters and fatty acids	HEFA	Vegetable oil, animal fats, used cooking oil	50 %
ASTM D7566 Annex A3	Synthesised iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass from sugar production	10 %
ASTM D7566 Annex A4	Synthesised kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	FT-SKA	Coal, natural gas, biomass	50 %
ASTM D7566 Annex A5	Alcohol to jet synthetic paraffinic kerosene	ATJ-SPK	Ethanol, isobutanol, and isobutene from biomass	50 %
ASTM D7566 Annex A6	Catalytic hydrothermolysis jet fuel	CHJ	Vegetable oil, animal fats, used cooking oil	50 %
ASTM D7566 Annex A7	Synthesised paraffinic kerosene from hadrocarbon - hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10 %
ASTM D7566 Annex A8	Synthetic paraffinic kerosene with aromatics	ATJ-SKA	C2-C5 alcohols from biomass	
ASTM D1655 Annex A1	co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery		Vegetable oil, animal fats, used cooking oil from biomass processed with crude oil	5 %
ASTM D1655 Annex A1	co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery		Fischer-Tropsch hydrocarbons processed together with crude oil	5 %
ASTM D1655 Annex A1	Co-Processing of HEFA	Hydroprocessed esters/fatty acids from biomass		10 %

Table 2: ASTM-certified production processes for synthetic fuels [53]

Co-processing: co-processing of alternative raw materials in the conventional refinery process

In addition to the eight SAF processes currently listed in the Annex to D7566, there are three further options for fuel production that utilise alternative raw materials. These are listed in Annex A1 of ASTM D1655 and relate to so-called co-processing. According to this process, vegetable oils, animal fats or Fischer-Tropsch-based hydrocarbons, for example, can be mixed and co-processed in a conventional petroleum refinery in the fuel production process [53].

In the co-hydroprocessing of esters and fatty acids, vegetable oils, animal fats or used edible oils may be added in a maximum proportion of 5 %. The same blending limit of 5 % applies to the co-hydroprocessing of Fischer-Tropsch hydrocarbons, which are processed together with crude oil. HEFA co-processing, on the other hand, may be carried out with a maximum blending percentage of 10 %. An overview of the processes is shown in Table 2. Efforts are currently being made to increase the maximum blending percentage from 5 % to 30 %. Furthermore, an evaluation scheme is being developed to facilitate the approval of new raw materials for co-processing and to be able to evaluate them separately from the approval process according to ASTM D4054 [53].

In addition, the ASTM subcommittee dealing with the specification of jet fuel has voted on an addition to a co-processing annex (WK78597) in D1655. Currently, the co-processing of non-conventional feedstocks is only possible for triglycerides, fatty acids and fatty acid esters as well as Fischer-Tropsch crude products (according to Annex A1 of ASTM D1655). With the co-processing of other raw materials, the proportion of renewable components in aviation fuel could be further increased [53].

Manufacturing process under development: Power-to-Liquid

The potential of Power-to-Liquid (PtL) fuels lies primarily in their high energy density, CO_2 neutral combustion, the possibility of a significant reduction in pollutant emissions and their drop-in capability in the existing infrastructure. In the following, only a brief overview of production using the PtL process will be given. For a detailed description and inventory of the individual synthesis methods and process steps, please refer to the innovation cluster "Production" of the InnoFuels project.

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The manufacture of PtL products is fundamentally based on the production of liquid fuels from hydrogen (H_2), which is produced in an electrolysis process using renewable energies. Regardless of the end product, the process steps are similar for all variants of a PtL process:

1. Provision of green H_2 and green CO_2 (i.e. RED II requirements must be met)
2. Production of the synthesis gas (H_2 + CO) by means of reverse water gas shift reaction (RWGS)
3. Conversion of the synthesis gas via FT process or via methanol route
4. Processing the raw product into a drop-in-capable fuel

The individual process steps are fundamentally known, albeit still at very different TRL levels. In particular, the FT process, the processing methods and parts of the methanol route (production of so-called olefins as an intermediate product) are already industrial standards and have been implemented in large-scale processes. Other process steps are not yet as advanced in terms of their technological maturity and therefore also in terms of their upscaling and efficiency. This applies in particular to the extraction of CO_2 from the air (DAC – Direct Air Capture), the RWGS process and the conversion of olefins from the methanol route to long-chain hydrocarbons. However, there is also still a need for further development in electrolysis, especially with regard to the yield of H_2 in comparison to the energy used or the electricity required.

Apart from the lack of upscaling of individual process steps, there is currently also a lack of demonstration of the complete PtL process chain from H_2 and CO_2 provision to the finished product. Individual test plants on a pilot and demo scale for the production of one FT raw product or MtJ in particular are known. However, no plant exists to date that has continuously produced a PtL product on at least a semi-industrial scale over a longer period of time.

Methods under ASTM approval

Many new processes for fuel production from non-conventional raw materials are currently being tested. These efforts are motivated, for example, by the desire to achieve lower production costs, to use cheaper and/or continuously available raw materials or to look at promising raw materials for which no effective conversion processes currently exist [54]. Table 3 provides an overview of production paths that are currently under development.

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Conversion process in evaluation	Abbreviation	Leading developers
Synthesised aromatic kerosene	SAK	Virent
Integrated hydropyrolysis and hydroconversion	IH2	Shell
Single Reactor HEFA (Drop-in Liquid Sustainable Aviation and Automotive Fuel)	DOLSAAF	Indian CSIR-IIP
Pyrolysis of non-recyclable plastics	ReOIL	OMV
Co-processing of pyrolysis oil from used tyres	TPO	Philips 66
Methanol to jet	MTJ	ExxonMobil
Increase in fatty acid/ester co-processing from 5 % to 30 %		
HEFA with higher cycloparaffins		Revo
Biomass pyrolysis		Alder
Biomass/Waste pyrolysis		Green Lizard
Cycloalkanes from ethanol		Vertimass

Table 3: Production process for synthetic fuels in the ASTM evaluation process [53]

Time and costs in the authorisation process

ASTM certification is a costly and time-consuming process. The testing of synthetic fuels takes several years due to the multi-stage approach of comprehensive data collection and review processes in accordance with D4054. To expedite the approval process for synthetic fuels, which have similar composition and properties to conventional jet fuel, ASTM has partnered with the University of Dayton Research Institute (UDRI) and the Federal Aviation Authority (FAA) to develop a "Fast Track" programme. The aim of the programme is to reduce the process to just one to two years [50].

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3.2 REACh registration at European level

In addition to international ASTM certification, registration by the European Chemicals Agency (ECHA) is important for placing aviation fuels on the market at European level. The EU regulation REACh (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulates the safe use of chemicals that are placed on the market. The responsibility for this lies with the manufacturers, importers and downstream users. They must submit comprehensive data and a corresponding risk assessment for the mandatory registration. If this is not the case, the chemicals will not be placed on the European market in accordance with the "no data - no market" principle [55].

The requirements of REACH apply to new substances, mixtures and known substances in new applications or production pathways, which therefore also applies to synthetic fuels. Substances in quantities of less than one tonne per year are exempt from the registration requirement. If these are used for scientific research and development, they are also exempt from the authorisations and restrictions [49].

4 Summary

Due to the international nature of aviation, the field of application of SAF must always be viewed from a global perspective. Through involvement in international aviation organisations such as the ICAO and IATA, their specifications and guidelines for the production and use of SAF are also of importance for Germany and German airlines. In addition, the relevant industry standards for the certification of manufacturing processes and aviation fuels are also set at international level, with the ASTM acting as the central institution. ASTM-certified fuels may also be used directly in Germany. At European level, new fuels must also be registered with the European Chemicals Agency (ECHA) before they can be placed on the market.

The legal situation regarding the criteria for the sustainable production of SAF is extensive at European level. These can be found in several aviation and climate-relevant directives and regulations, which were jointly adopted by the EU member states as part of the European Green Deal and aim to increase the use of sustainable fuels in aviation. The use of these fuels is to be promoted through fixed quotas. The core element of this is the ReFuelEU Aviation Regulation, which defines, among other things, which fuels are permitted

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to fulfil the quotas. The corresponding sustainability criteria are set out in the Renewable Energy Directive (RED).

In addition to the comprehensive regulatory instruments of the EU, there are a number of other legislative and strategic elements in Germany relating to the production and use of SAFs. The transposition of the RED Regulation into national law is reflected in the Federal Immission Control Act (BImSchG). National strategies exist for hydrogen, for example, which is of fundamental importance for the market ramp-up as a basic element for SAF production using the PtL process. A national strategy for biomass is still at the draft stage.

With the current coalition agreement, the promotion of alternative fuels is also anchored in the current government programme, but recent developments in the federal budget have led to corresponding cuts in the funding budgets. In principle, the "Climate-neutral flying" programme is to remain firmly anchored in the Climate and Transformation Fund (KTF). However, a successful and, above all, rapid market ramp-up will only be possible with appropriate political measures for funding and acceptance. In addition, the summary of existing framework conditions (see also Table 4) for the market ramp-up of SAF has shown that regulatory measures can also harbour obstacles. The next step is to identify these and analyse their significance, which will be the subject of the follow-up report in the focus area “Application in Aviation” as part of InnoFuels.

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	International	European Union	Germany	USA
GHG reduction targets	**Paris Agreement 2015** Limiting the global temperature rise to well below 2 °C, if possible even below 1.5 °C compared to pre-industrial levels **Net Zero Carbon 2050 Resolution (IATA, 2021)** Net zero CO_2 emissions from 2050 **LTAG (ICAO, 2022)** Net-zero CO_2 emissions for international aviation by 2050 (no specific reduction targets for individual countries) **Global framework of the ICAO** Reduction of CO_2 emissions in international aviation by 5 % by 2030	**European Green Deal** Climate neutrality in the EU by 2050 **Fit-for-55 package** Reduction of GHG emissions by 55 % by 2030 compared to 1990	**Federal Climate Protection Act*** Gradual reduction of GHG emissions compared to 1990 - by at least 65 % by 2030 - by at least 88 % by 2040 - Net GHG neutrality by 2045 - Negative emissions after 2050	**Inflation Reduction Act** Reduction of CO_2 emissions by around 40 % by 2030 compared to 2005
Measures to achieve targets in relation to SAF	**Global framework** - Vision 2050 for sustainable fuels - Harmonised regulatory principles - Supporting initiatives - Improved access to funding - SAF goals and guidelines - Support from member states - Information, best practice - ACT-SAF programme **IATA's 4-pillar strategy** - Use of SAF and utilisation of compensation measures as two of four	**Regulation ReFuelEU** - Increasing the use of SAF in air traffic - Specification of blending quotas and penalties for non-compliance - Definition of authorised fuels for quota fulfilment - Reference to RED criteria	**Federal Immission Control Act (BImSchG)** PtL blending quota for air traffic: - 0.5 % by 2026 - 1 % by 2028 - 2 % by 2030 - Penalty **National Hydrogen Strategy (NWS)** - Nat. production target for 2030: 10 GW hydrogen - Hydrogen demand by 2030 approx. 95-130 TWh - Import quota 50-70 % (45-90 TWh) - Use of PtL fuels **National Biomass Strategy (NABIS)** - Development of framework conditions with a steering effect	**Renewable Fuel Standard 2 (RFS2** - Volume commitments for US-based refineries, blenders and importers of renewable fuels **FAST programme** - FAST-SAF and FAST-Tech - Goal: Accelerate the production and utilisation of SAF **SAF Credit** - Tax credit for the sale of qualified fuel blends with sustainable aviation fuel

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			- Current draft version **PtL roadmap of the German government** - Target: at least 200,000 tonnes of PtL kerosene for German aviation by 2030	
Definition of sustainability standards	**Eligibility criteria for CORSIA Eligible Fuels (CEF)** - Environmental standards within the framework of CORSIA (ICAO)	**Renewable Energy Directive (RED) + Delegated acts** - EE Directive - Sustainability criteria - Requirements for SAF production **EU Taxonomy Regulation** Definition of environmentally sustainable economic activities (since 2023 extended to include air transport operations under certain conditions)	**Federal Immission Control Act (BImSchG)** Transposition of the RED from EU level into national law	**Renewable Fuel Standard 2 (RFS2)** - Sustainability standards for renewable fuels - Specifications for admixture - RINs as tradable certificates
Climate compensation systems* * Voluntary CO_2 offsetting options aimed at air passengers are not considered here	**CORSIA (ICAO)** - Applies to all civil, international flights connecting two participating countries - Out-of-sector measure - Crediting of SAF utilisation possible	**European Emissions Trading Scheme (EU ETS)** - Applies to all flights taking off or landing within the EEA - Cap-and-trade principle - Emission allowances for the use of SAFs ("SAF Allowances")		
Industry standards required for SAF	**Process standard ASTM D4054** for new synthetic fuels **Fuel certification according to ASTM** each with worldwide validity	**ECHA Registration** according to EU regulation REACh	Inclusion in BImSchV not required due to ASTM standards	See ASTM Standards

Table 4: Summary of the framework conditions for the SAF market ramp-up

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List of abbreviations

Abbreviation	Meaning
ACT	Assistance, Capacity-building and Training
ASCENT	Aviation Sustainability Centre
ASTM	American Society for Testing and Materials
ATAG	Air Transport Action Group
AtJ	Alcohol-to-Jet
BDL	Federal Association of the German Air Transport Industry (Bundesverband der Deutschen Luftverkehrswirtschaft e.V.)
BImSchG	Federal Immission Control Act (Bundes-Immissionsschutzgesetz)
BImSchV	Federal Immission Control Ordinance (Bundes-Immissionsschutzverordnung)
BMDV	Federal Ministry for Digital and Transport Affairs (Bundesministerium für Digitales und Verkehr)
BMEL	Federal Ministry of Food and Agriculture (Bundesministerium für Ernährung und Landwirtschaft)
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz)
BMWK	Federal Ministry of Economics and Climate Protection (Bundesministerium für Wirtschaft und Klimaschutz)
BMZ	Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung)
CAA	Clean Air Act
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAEP	Committee on Aviation Environmental Protection
CBAM	Carbon Border Adjustment Mechanism

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CCS	Carbon Capture and Storage
CEF	CORSIA Eligible Fuel
CLEEN	Continuous Lower Energy, Emissions, and Noise Programme
CO	Carbon
CO_2	Carbon dioxide
CO_2eq/MJ	CO_2 equivalent per megajoule
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DAC	Direct Air Capture
DLR	German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt e.V.)
ECHA	European Chemical Agency
EEA	European Economic Area
EU	European Union
EU ETS	European emissions trading system
FAA	Federal Aviation Authority
FAST	Fueling Aviation's Sustainable Transition
FDP	Free Democratic Party
FT	Fischer-Tropsch
GHG	Greenhouse gases
GW	Gigawatt
H_2	Hydrogen
HEFA	Hydroprocessed Esters and Fatty Acids
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IRA	Inflation Reduction Act
IRS	Internal Revenue Service

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KTF	Climate and transformation fund (Klima- und Transformationsfonds)
LCAF	Low Carbon Aviation Fuels
LRF	Linear reduction factor
LTAG	Long-Term Aspirational Goal
MRV	Monitoring, Reporting and Verification
MtJ	Methanol-to-jet
NABIS	National Biomass Strategy (Nationale Biomassestrategie)
NWS	National Hydrogen Strategy (Nationale Wasserstoffstrategie)
PtL	Power-to-Liquid
PtX	Power-to-X
RCF	Recycled carbon fuels
RE	Renewable energies
REACh	Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation
RED	Renewable Energy Directive
RFS2	Renewable Fuel Standard 2
RIN	Renewable Identification Number
RFNBO	Renewable fuels of non-biological origin
RWGS	Reverse water gas shift reaction (reverse water gas shift reaction)
SAF	Sustainable Aviation Fuels
SCS	Sustainability Certification Schemes
SKA	Synthesized Kerosene with Aromatics
SPD	Social Democratic Party of Germany (Sozialdemokratische Partei Deutschlands)
SPK	Synthetic Paraffinic Kerosene
TRL	Technology Readiness Level

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TWh	Terawatt hours
UDRI	University of Dayton Research Institute
UN	United Nations
USD	US dollar

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