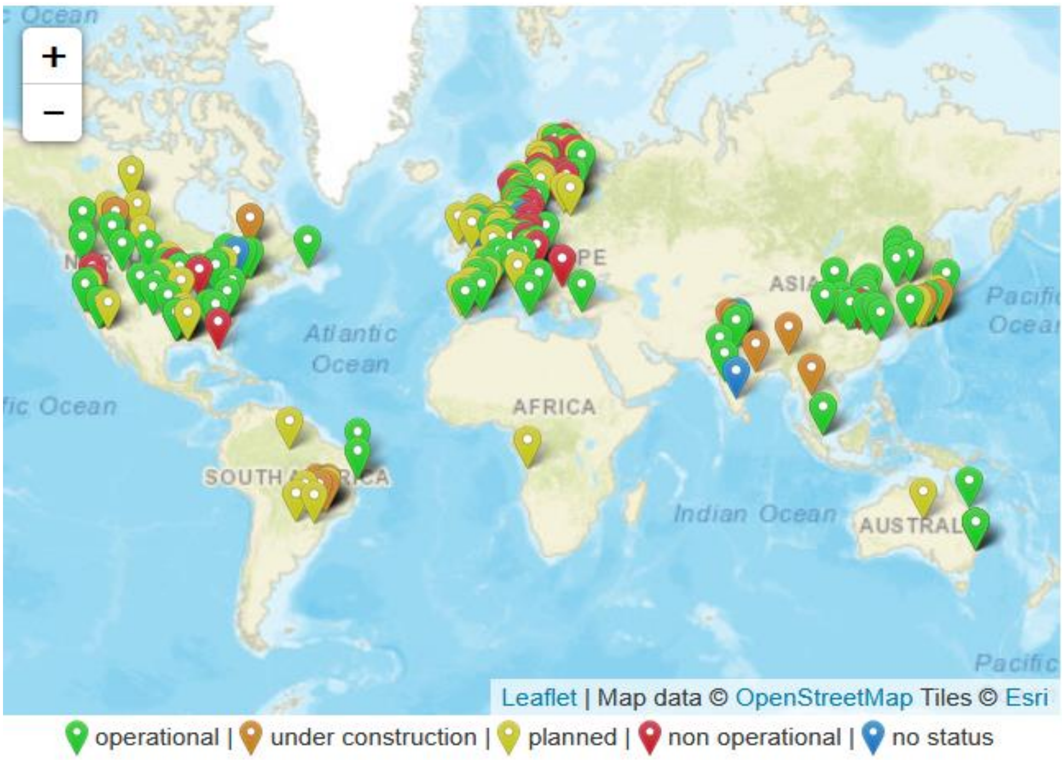
# Development and Deployment of advanced biofuel demonstration facilities

IEA Bioenergy: Task 39

December 2024



# Development and Deployment of advanced biofuel demonstration facilities

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# Executive Summary

Decarbonizing the transport sector is critical for achieving global climate and energy targets due to its significant contribution to greenhouse gas emissions and reliance on fossil fuels. Biofuels, in particular advanced biofuels, play a particularly important role in decarbonizing transport and increasing the share of renewable energy in the transport sector by providing a low-carbon solution for both near-term and long-term challenges.

One of the tasks in the Technology Collaboration Programme IEA Bioenergy deals with Biofuels to Decarbonize Transport. Within this expert network a Database on facilities for the production of advanced liquid and gaseous biofuels for transport was established and has monitored the developments since 2009. This database comprises facilities which are producing advanced biofuels via the technologies Alcohol-to-Jet, E-Fuels Biomass Hybrids, Fast Pyrolysis, Fermentation, Gasification, Hydrothermal Liquefaction, Hydrotreatment and others. The latest update of the database was completed in November 2024. At this time the database comprised 258 active entries, related to the different technologies listed above. This report provides insights from the monitoring and data collection on advanced biofuel demonstration facilities throughout the years.

The main (and most advanced) technologies used for advanced biofuel production are fermentation to cellulosic ethanol, hydrotreatment of oils and fatty acids, gasification followed by FT-synthesis and fast pyrolysis. Of these technologies, hydrotreatment is the most commercialised one with many production facilities around the globe and the highest production capacities. Hydrotreatment facilities are also the main production facilities for sustainable aviation fuels.

Co-processing of fats, oils and lipids in existing refineries and retro-fitting of existing refineries for the processing of these feedstocks is gaining more importance. Another technology option which is increasing in number of (planned) facilities is the combination of e-fuel production and biomass use – so-called E-fuels biomass hybrid facilities.

Feedstock availability is a critical factor in the production of biofuels, as it determines both the scalability and sustainability of fuel production. While oil-based residues, such as used cooking oil and animal fats, are valuable for current biofuel technologies, their limited supply poses a significant challenge to meeting future demand. To address this, biomass residues, including agricultural waste, forestry by-products, and other organic materials, present a promising alternative, and their potential needs to be unlocked by the development, demonstration and commercialization of advanced biofuels production technologies.

Besides the availability, also the sustainability of dedicated crops, residues and wastes are an important factor. Many countries have implemented frameworks to safeguard biofuel sustainability. It is essential that those policy frameworks ensure robust GHG emission certification and verification.

The primary future markets for advanced biofuels are expected to be in long-distance transport sectors, such as aviation, maritime shipping, and heavy-duty road transport. The aviation industry, in particular, requires a strong focus on renewable fuels and biofuels as the sector continues to grow and has committed to reduce its carbon intensity.

Research and policy frameworks have been crucial in driving the development of demonstration plants for advanced biofuel technologies. These frameworks have influenced investment decisions and significantly impacted the success or failure of such initiatives.

The development of biofuels is accelerating in emerging economies, driven by increasing energy demand, abundant natural resources, and the need for sustainable development. These countries are focusing on biofuels as a means to address both energy security and climate change. To support this transition, governments are implementing various policies, including blending mandates and subsidies, to boost biofuel production. These efforts are aimed at promoting renewable energy sources while simultaneously creating new economic opportunities and reducing reliance on fossil fuels. As these policies gain traction, biofuel production is becoming a more significant component of their energy strategies.

Decarbonization targets require a significant increase in biofuel production to meet global climate goals. Recent years have seen a surge in announcements of new biofuel production facilities, particularly for HVO (Hydrotreated Vegetable Oils) and SAF (Sustainable Aviation Fuel); technologies critical for sectors like aviation, shipping, and heavy freight, where electrification is difficult. However, while some technologies, such as hydrotreatment, have reached commercial scale, others like cellulosic ethanol face slow progress and setbacks. Despite many announcements, the actual production capacity is not growing quickly enough to meet the ambitious targets set for 2030. This gap highlights the challenge of scaling up biofuel production to match the urgent demands of the energy transition.

Scaling up advanced biofuel production is a global challenge that requires addressing environmental, social, and economic sustainability. This process can be accelerated through international collaboration and knowledge exchange. Demonstrating and scaling up biofuel technologies is crucial to achieving the large production volumes needed to meet global decarbonization targets, especially in sectors that are hard to electrify, such as aviation, shipping, and heavy-duty transport. Without advancing these technologies and expanding production capacity, the full potential of biofuels to contribute to a sustainable energy future will remain untapped.

**Biofuels and advanced biofuels play an important role in decarbonizing the transport sector**

**Advantages of advanced biofuels:** Advanced biofuels pose many advantages like the variety of technologies and feedstocks/residues that can be used, the possible integration in existing fleets and infrastructure and their high energy density and storability.

**Need for Commercialization:** For commercialization of advanced biofuels the demonstration and scale-up, as well as building up capacity and production volumes are necessary. The reduction of costs and financial risks is essential and long-term policies and comprehensive strategies are needed to lead the way to commercialization.

**Promising opportunities and developments:** The promising opportunities and positive developments for advanced biofuels are the increasing demand and production in emerging economies and the defossilization in long-distance transport, like in the aviation, maritime and heavy-duty sector.

# Index

## Abbreviations

| | |
|---|---|
| AMF | Advanced Motor Fuels |
| ATJ | alcohol-to-jet |
| BECCUS | Bioenergy with carbon capturing, utilizing and sequestration |
| CFS | Clean Fuel Standard |
| CI | Carbon intensity |
| CORSIA | Carbon Offsetting and Reduction Scheme for International Aviation |
| ETIP | European Technology and Innovation Platform |
| EU-ETS | EU - Emission Trading System |
| FAME | Fatty acid methyl ester |
| FT | Fischer Tropsch |
| GHG | Greenhouse gas |
| HEFA | Hydroprocessed esters and fatty acids |
| HTL | Hydrothermal liquefaction |
| HVO | Hydrotreated vegetable oil |
| IEA | International Energy Agency |
| IRA | Inflation Reduction Act |
| LCFS | Low Carbon Fuel Standard |
| NZE | Net Zero Emissions by 2050 |
| PtL | Power-to-Liquid |
| RCFs | recycled carbon fuels |
| RD (HVO) | Renewable Diesel (Hydrotreated Vegetable Oil) |
| RED | Renewable Energy Directive |
| RFNBOs | renewable fuels of non-biological origin |
| RFS | Renewable Fuels Standard |
| SAF | Sustainable Aviation Fuel |
| TCP | Technology Collaboration Programmes |
| TRL | Technology Readiness Level |

# Introduction

The decarbonisation of the transport sector is an important part of the global climate and energy targets. This sector is a major contributor to greenhouse gas emissions, accounting for a significant portion of global carbon dioxide output due to its reliance on fossil fuels like gasoline and diesel. These emissions not only accelerate global warming but also degrade air quality, leading to severe public health issues such as respiratory and cardiovascular diseases. Rapid urbanization and increasing mobility demand further exacerbate the problem, highlighting the need for immediate action.

Transitioning to low-carbon or zero-emission alternatives, such as electric vehicles, biofuels, public transit systems, and active transportation like cycling, can significantly reduce these emissions and decreases reliance on non-renewable energy sources, enhancing energy security. Moreover, it drives innovation, creating economic opportunities in clean energy and sustainable infrastructure while aligning with global climate goals like those outlined in the Paris Agreement. Addressing emissions in the transport sector is essential to meet global climate targets, protect ecosystems, and create resilient, low-carbon economies for future generations.

Biofuels play a particularly important role in decarbonizing transport and increasing the share of renewable energy in the transport sector by providing a low-carbon solution for both near-term and long-term challenges. Biofuels are already making a substantial contribution in this area, immediately reducing emissions from the existing vehicle fleet. The development of technologies for producing advanced biofuels from biomass and residual materials aims to expand production and achieve greater GHG emission reductions in the transport sector.

Liquid Biofuels are especially critical for hard-to-abate sectors such as trucking, shipping, and aviation, which have few cost-effective alternatives to reduce emissions. In road transport, biofuels will represent a short and medium-term solution, while in long-distance transport, which is more difficult to electrify, liquid biofuels with high energy density will also be needed in the long term to replace fossil fuels. Biofuels can often be used in existing engines with minimal modifications, offering a seamless integration into current systems while leveraging established infrastructure for storage and distribution.

In 2022, global biofuel demand reached a record high of 4.3 EJ (170,000 million liters), surpassing pre-pandemic levels from 2019, highlighting their growing importance in the push for sustainable transportation. In the Net Zero Scenario of the IEA the use of biofuels in the transport sector rises significantly to 2030 with a production over 10 EJ, requiring an average growth of more than 10% per year. The use of advanced biofuels needs to increase; biofuels produced from waste, residues and non-feed energy crops meet over 40 % of total biofuel demand by 2030, whereas the share in 2021 was around 9% (IEA, 2023 a). With regard to the transport sectors, the demand for shipping and aviation fuels will increase until 2050. Whereas the demand for liquid fuels in road transport will decrease, according to the announced pledges scenarios of the IEA Energy Technology Perspectives (IEA, 2024 a).

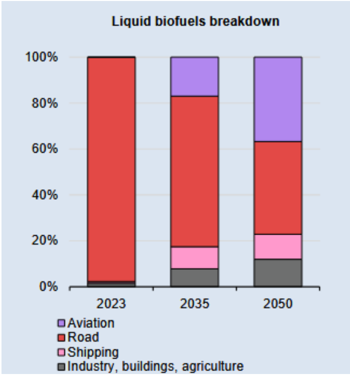

*Figure 1 share of liquid biofuels per sector*

A range of liquid biofuels is needed to meet this demand. In terms of sustainability and competition for raw materials, hopes are pinned on advanced biofuels. Unlike first-generation biofuels, which are derived from food crops, advanced biofuels are produced from non-food biomass, such as agricultural residues, waste, and dedicated energy crops. This minimizes competition with food production and reduces land-use impacts. Moreover, advanced biofuels can achieve higher greenhouse gas (GHG) emission reductions, making them a more effective tool for meeting stringent climate targets.

Former participants of IEA Bioenergy Task 39 posed the question 'How close are second-generation biofuels' back in 2010 (Bacovsky et al., 2010 a) and back then concluded that it seemed that they are a few years away from commercialization. The assumption was that once the technology has been successfully demonstrated at scale, the industry should see predictable but accelerated growth. Successful demonstration within 24 months should lead to significant production volumes and commercial uptake within one or two years. Unfortunately, this has not proved to be the case and the commercialisation process is lagging behind. To track the developments and the commercialization progress, IEA Bioenergy Task 39 implemented a database on demonstration facilities, which is described in the following chapter.

After picturing the background and intention, the framework of IEA Bioenergy Task 39 and the database on demonstration facilities is presented. The objectives and definitions are clarified and the different advanced biofuels technologies are elaborated. After this introductory chapters the assessment of demonstration and deployment of advanced biofuel production and recent developments are presented, as well as the importance of scale up and demonstration, implementation barriers and opportunities for advanced biofuels. The report ends with and outlook for demonstration of advanced biofuels production. The listed facilities from the database can be found in the annex.

## IEA BIOENERGY TASK 39 – BIOFUELS TO DECARBONIZE TRANSPORT

IEA Bioenergy Technology Collaboration Programme

IEA Bioenergy is one of the Technology Collaboration Programmes (TCP) within the framework of the International Energy Agency. The goal is to facilitate the commercialisation and market deployment of environmentally sound, socially acceptable and cost-competitive bioenergy systems, thereby enhancing energy security and reducing greenhouse gas emissions. It provides a platform for international collaboration and information exchange between countries on bioenergy research, technology development, demonstration and policy analysis.

The work of IEA Bioenergy is structured in a number of Tasks, one of them being IEA Bioenergy Task 39 – Biofuels to Decarbonize Transport. More information can be found at: https://task39.ieabioenergy.com/.

IEA Bioenergy Task 39 is a network of international experts that aims to drive forward the decarbonization of transport with the help of sustainable biofuels, with an increasing focus on the long-distance transport sector (aviation, shipping, heavy duty vehicles), which is more difficult to electrify. The goal of Task 39 is to support the development and deployment of transportation biofuels by addressing both technical and infrastructure challenges. Its objectives include providing analysis on policies, markets, and implementation to promote sustainable conventional biofuels and advance the commercialization of liquid biofuels as alternatives to fossil fuels. Task 39 also fosters collaborative R&D to improve cost-effective production processes for advanced biofuels and engages in information dissemination, stakeholder outreach, and coordination with related organizations.

In the current working period (2022-2024) IEA Bioenergy Task 39 comprises 16 participants/

member countries across the different continents and time zones: Austria, Belgium, Brazil, Canada, China, Denmark, European Commission, Germany, Ireland, Japan, New Zealand, South Korea, Sweden, Netherland, United States and as limited sponsor the US Grains Council.

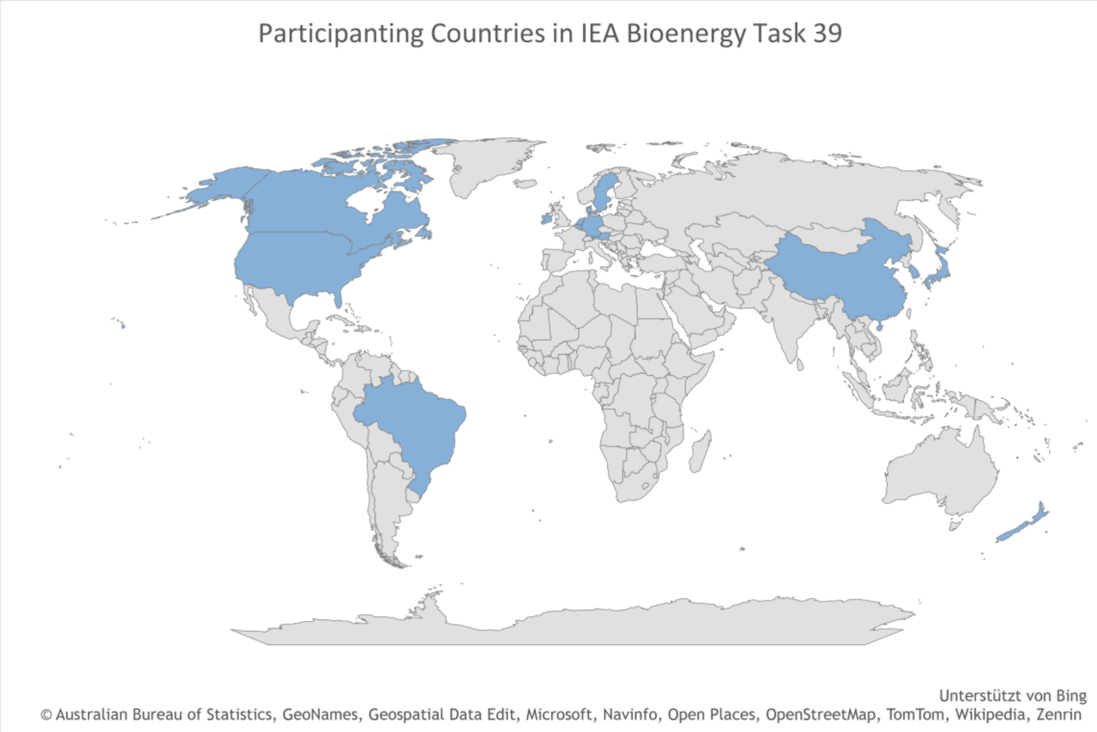


*Figure 2: Participating countries in IEA Bioenergy Task 39 2022-2024*

The projects or topics worked on in IEA Bioenergy Task 39 include technologicial topics (SAF/biojet, drop-in fuels, marine fuels, synergies with green hydrogen), market-related topics (demonstration facilities, commerzialisation progress, emerging economies), policy related topics (implementation agendas, biofuel policies) and sustainability issues (certification, sustainable biofuel implementation).

One of the projects is the Assessment of demonstration plants and commercialisation progress, led by Austria. The objective of this project is the monitoring and tracking of demonstration plants and commercialization progress of advanced biofuels in the Task 39 member countries and worldwide. The core part of this project is a database on facilities for the production of advanced liquid and gaseous biofuels for transport, which will be described in the next chapter.

## DATABASE ON DEMONSTRATION OF ADVANCED BIOFUELS

IEA Bioenergy Task 39 established a database on facilities for the production of advanced biofuels back in 2009 which can be found on the following website: https://demoplants.best-research.eu/. With this project Task 39 provides a global overview of facilities for the production of advanced biofuels on pilot or demonstration scale assessing and monitoring commercialization progress.

This mapping of 2nd Generation Biofuel Demonstration Plants started in 2009 as interactive map listing with more than 50 plants producing advanced biofuels via thermochemical (gasification), biochemical (fermentation) or hybrid pathways. Filtering options were possible on technology, type and status. In 2010 a report on the Status of 2nd generation Biofuels

Demonstration facilities was published (Bacovsky et al., 2010 b). This report has been updated and supplemented and published as Status of Advanced Biofuels Demonstration Facilities in 2012 (Bacovsky et al., 2013). The latter report was translated into Chinese in 2013 by COFCO (COFCO, 2013).

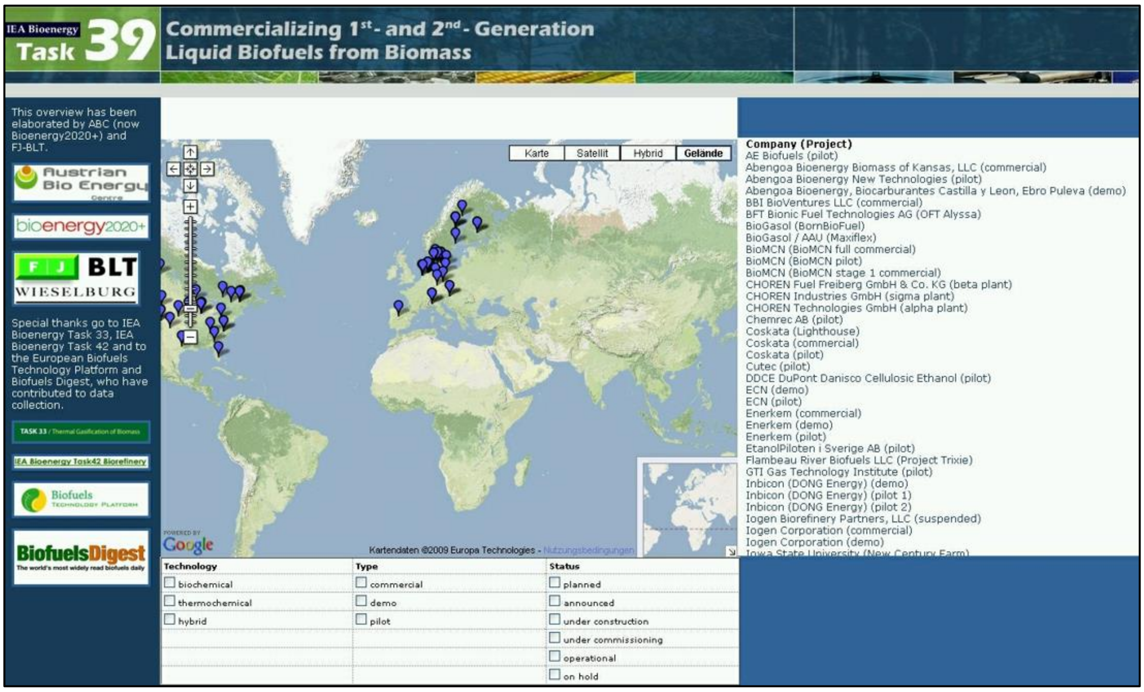


*Figure 3: Screenshot of the first appearance of the Task 39 database*

Since then Task 39 regularly updated its pilot and demonstration plants database and the development of advanced biofuel technologies and facilities as well as the commercialization progress has been monitored and assessed. The database also serves as a data source for other institutions, like NREL, IEA, JRC. The information listed in the Task 39 database is used by many stakeholders and is also repeatedly used as database in scientific publications. IEA Bioenergy uses the Task 39 database, as well as similar databases from Task 32, 33, 34 for their Global database of biomass conversion facilities, including advanced biofuels, combustion, gasification and pyrolysis plants. In addition the European facilities of those tasks are listed the production facilities map of ETIP Bioenergy.

The database offers insights into the locations and operations of advanced biofuels production facilities across Task 39 member countries and, wherever feasible, beyond. The database is systematically updated twice per triennium. This update comprises four different elements: collating information from Task 39 participants, collating information from other groups, own research for updating outdated information, and critical review of data and integration into the database. The input and information for the regular update of the database is coming from the Task 39 members spread over these countries (Austria, Belgium, Brazil, Canada, China, Denmark, European Commission, Germany, Ireland, Japan, New Zealand, South Korea, Sweden, The Netherlands and USA) and input from the working groups of the European network ETIP Bioenergy. Further contacts via the IEA Advanced Motor Fuels TCP are used. While in the beginning publicly available information on the advanced biofuels demonstration projects was very rare, and direct contacts to the companies pursuing these projects were key, nowadays most companies publish information on their projects on their websites. A key asset of the Task 39 database though is that the information provided is verified through the involvement of Task 39 experts from countries all over the world.

The database in its current form is titled Database on facilities for the production of advanced liquid and gaseous biofuels for transport and includes following technologies: Alcohol-to-jet, E-Fuels Biomass Hybrids, Fast Pyrolysis, Fermentation, Gasification, Hydrothermal Liquefaction, Hydrotreatment, Lignin Depolymerization and Other Technology.

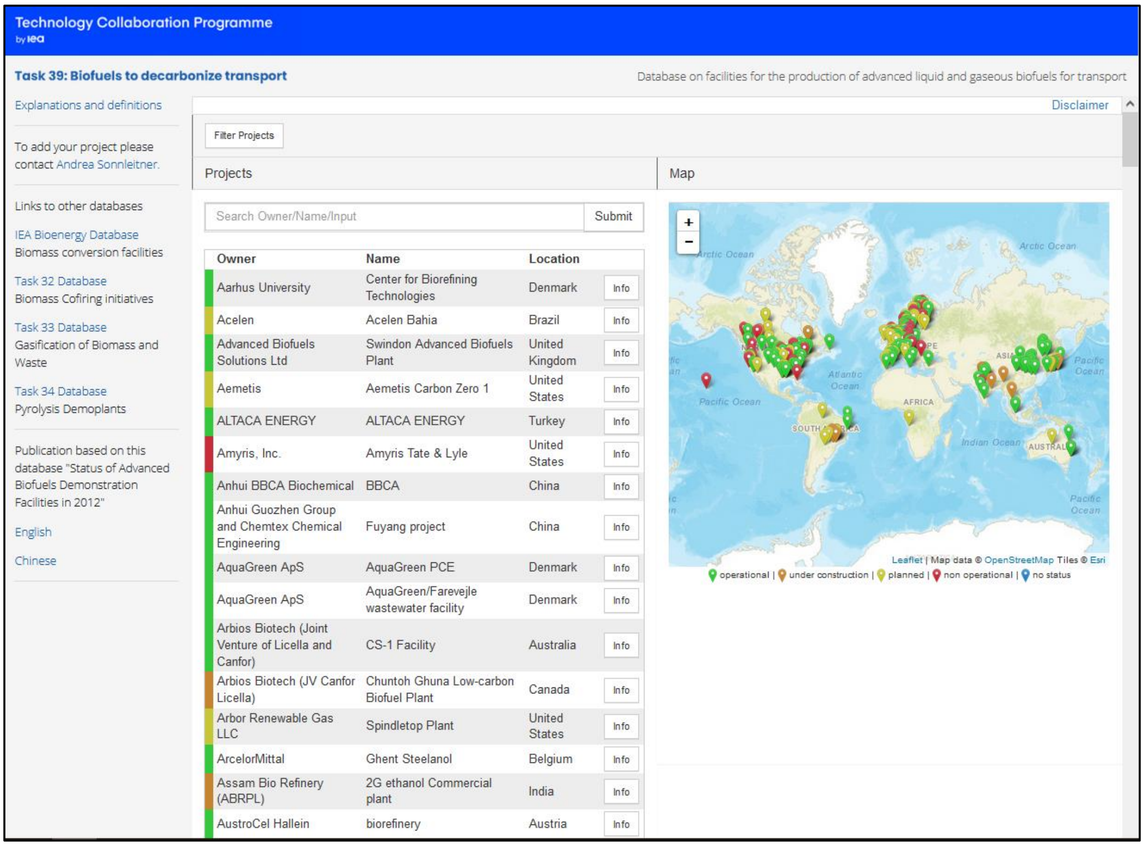


*Figure 4: Database on facilities for the production of advanced liquid and gaseous biofuels from transport*

At the website of the database different categories for each facility are displayed and it is possible to search and filter according to the various categories. The possible filter options are displayed in the following figure.

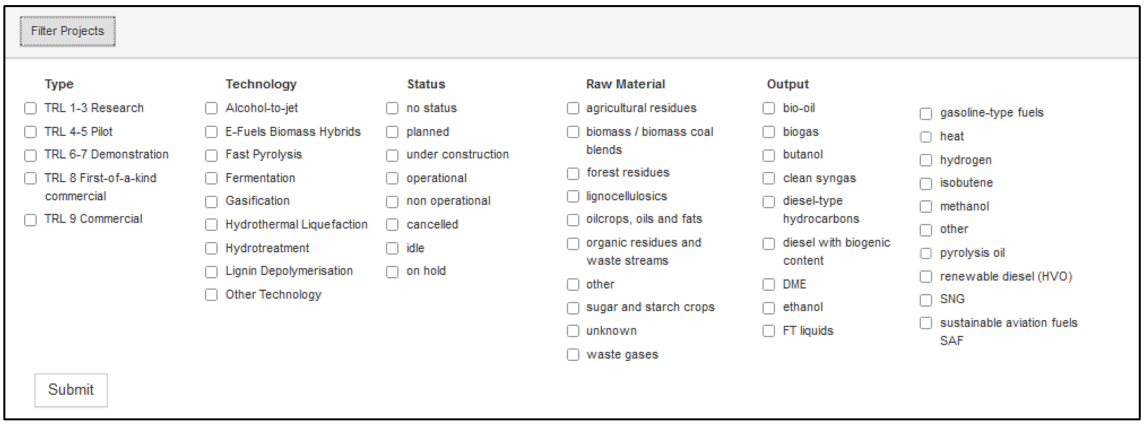


*Figure 5: Filter options for the Task 39 Demoplants Database*

In addition to this overall categories, more detailed information on the facilities and projects is available and listed on the Info-page of the respective data entry. The project information includes at least the required minimum data and, optionally more detailed information:

*Table 1: Collected information for the Task 39 Demoplants Database*

| | |
|---|---|
| **Minimum data** | Project name and project owner<br>Location of the production facility<br>Type of technology<br>Raw material<br>Product<br>Output capacity<br>Type of facility<br>Status and<br>Contact information |
| **Optional data** | Start up year<br>Additional information on technology and input capacity<br>Information on investment and funding<br>Partners<br>Brief technology description<br>Flow sheets, pictures |

## Objectives and Definitions

This report shows the insights of the monitoring and data collection of advanced biofuel demonstration facilities throughout the years. The status of facilities for the production of advanced liquid and gaseous biofuels for transport is mapped, and developments are highlighted. Analysis and critical review highlight the influence of policy frameworks on technology development and the deployment of advanced biofuels production facilities.

The ongoing assessment and tracking of demonstration plants and commercialization progress continues, with the successes and lessons-learned from cellulosic ethanol and other advanced biofuel pioneer plants applied to emerging technologies and processes. This includes reviewing the status of conventional and advanced biofuels demonstration and commercial facilities that are planned, under construction, operating or closed. Continued analyses will be carried out on those key issues which have limited the integration of conventional and advanced biofuels into existing production and use.

In this report we are using definitions of IEA Bioenergy and IEA Bioenergy Task 39 regarding bioenergy, biomass and biofuels. **Bioenergy** is renewable energy derived from biomass. Biomass is defined as biological material which is directly or indirectly produced by photosynthesis. Examples are wood and wood residues, energy crops, crop residues, and organic waste/residues from industry, agriculture, landscape management and households. The biomass is converted to solid, liquid or gaseous fuel which can be used to produce heat and/or electricity, or can be used as transport fuel.

**Biofuels** are liquid fuels produced from biomass and serve as alternatives to fossil fuel-based transportation fuels like gasoline, diesel, and aviation fuel. While some organizations use the term "biofuels" to refer to solids, liquids, and gases used in bioenergy production, the IEA Bioenergy Implementation Agreement, Task 39, adopts a more specific definition, focusing solely on liquid transportation biofuels due to the wide variety of bioenergy forms and their distinct applications.

**Conventional biofuels** are well-established in terms of technology and market presence, and are commercially available. These biofuels, commonly referred to as first-generation, include sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion. The feedstocks for these biofuels typically include sugars, starches, oil-bearing crops, and animal fats, which can sometimes also be used as food or animal feed. However, further advancements in feedstock production and processing could help lower costs and improve environmental performance.

**Advanced biofuels** are produced using pre-commercial technologies that rely on non-food crop feedstocks or residues/waste. Some of those technologies are still in the research and development, pilot or demonstration phase, commonly referred to as second- or third generation. These biofuels are derived from materials such as agricultural and forest residues, which are primarily composed of cellulose, hemicellulose, and lignin. Advanced biofuels are capable of delivering significant lifecycle greenhouse gas (GHG) emissions reductions compared to fossil fuel alternatives. They are designed to avoid direct competition with food and feed crops for agricultural land and have no adverse sustainability impacts. These fuels can be blended with petroleum-based fuels, combusted in existing internal combustion engines, and distributed through current infrastructure, or they can be used in slightly modified vehicles. Advanced biofuels can be made from waste materials and oils, wheat and corn stalks, wood, and dedicated energy crops. Ongoing developments include cellulosic ethanol, hydrotreated vegetable oil, biomethanol, Fischer-Tropsch diesel, mixed alcohols, or even fuels which are still in the early stages of development like algal biofuels and hydrogen from biomass.

Another important definition which is used in the mapping of demonstration plants and projects is the definition of the **Technology Readiness Level** (TRL):

*Table 2: Definition of Technology Readiness Level used in the Task 39 Database*

| Type | Refers to technology readiness level (TRL) |
|---|---|
| TRL 1-3 Research | 1. basic principles observed<br>2. technology concept formulated<br>3. experimental proof of concept |
| TRL 4-5 Pilot | 4. technology validated in lab<br>5. technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies) |
| TRL 6-7 Demonstration | 6. technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)<br>7. system prototype demonstration in operational environment |

| Type | Refers to technology readiness level (TRL) |
|---|---|
| TRL 8 First-of-a-kind commercial demo | 8. system complete and qualified |
| TRL 9 Fully commercial | 9. Actual system proven in an operational and competitive environment |

## Advanced Biofuels Technology Options

As defined in the prior chapter, advanced biofuels in the frame of the IEA Bioenergy Task 39 Database are liquid fuels derived from biomass or biomass-derived residues. The different advanced biofuel production routes show different Technology Readiness Levels and commercialisation stages. Production routes for biofuels and their stage of development are shown in the following figure:

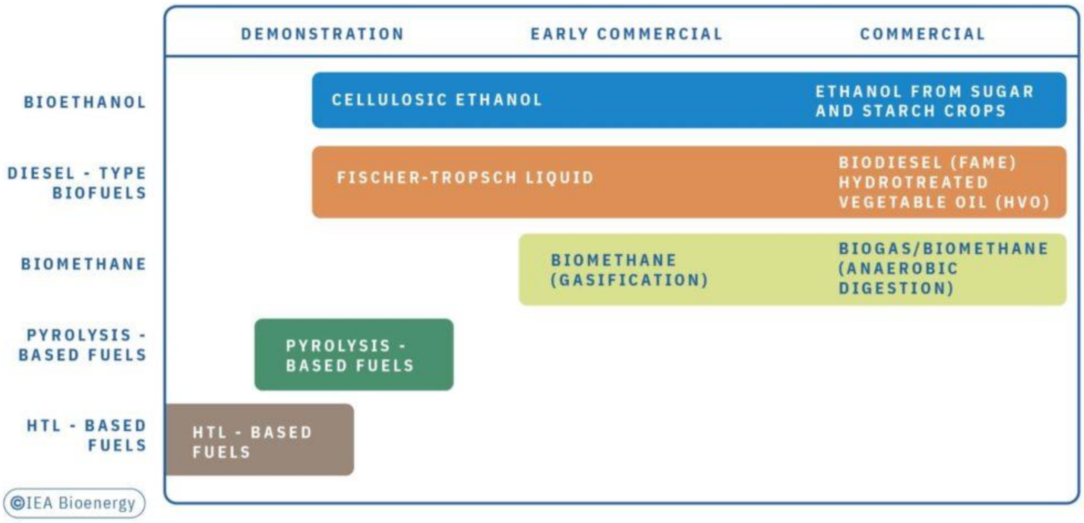


*Figure 6: Overview of technology pathways and their technology readiness level (IEA Bioenergy, 2023)*

There are many different biofuel production routes which can be used to convert a range of raw biomass feedstocks into a biofuel for transport as final energy use.

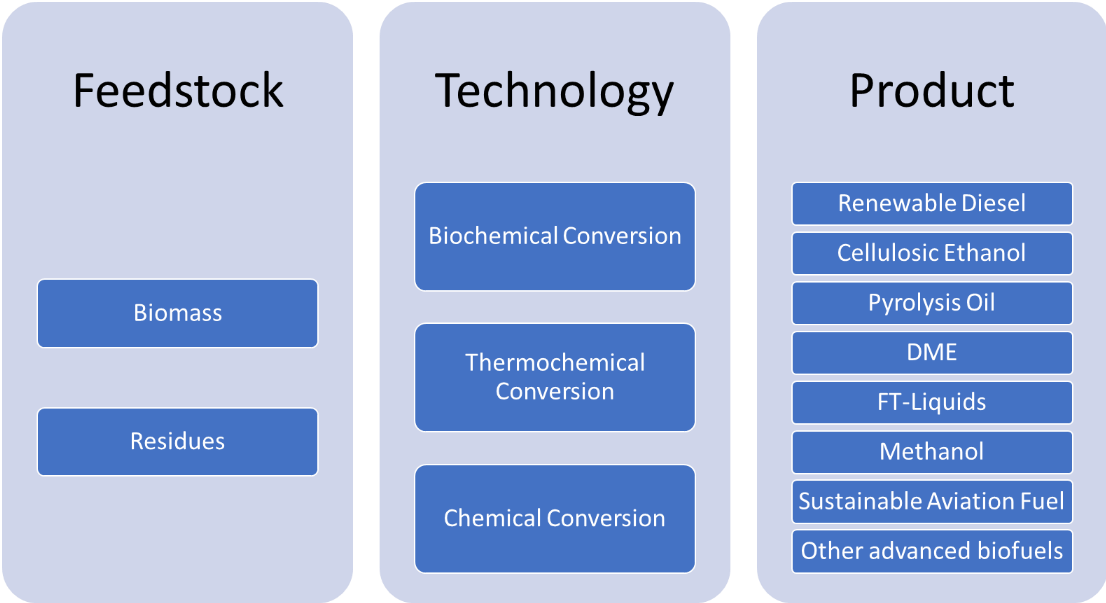


*Figure 7: Principle pathways of advanced biofuels technologies*

The following technology options are included in the mapping of facilities for the production of advanced liquid and gaseous biofuels for transport:

- Alcohol-to-jet
- E-Fuels Biomass Hybrids
- Fast Pyrolysis
- Fermentation
- Gasification
- Hydrothermal Liquefaction
- Hydrotreatment
- Lignin Depolymerisation
- Other Technology

Details on technology production can be found in various Task 39 reports and other sources like the Progress in Commercialization of Biojet/Sustainable Aviation Fuels (SAF): Technologies and policies (van Dyk and Saddler, 2024), the Update on drop-in biofuel and co-processing commercialization (van Dyk et al., 2024), Status of Advanced Biofuels Demonstration Facilities in 2012 (Bacovsky et al., 2013), Monitoring renewable energies in transport (DBFZ, 2023) or Advanced Biofuels in the European Union (EC JRC,2024).

## Assessment of Demonstration Plants and Commercialization Progress

Currently, the most widely used biofuels include ethanol and biodiesel, which are primarily conventional biofuels produced from food crops such as corn, sugarcane, and soybeans. Ethanol is commonly blended with gasoline, while biodiesel serves as a renewable alternative to diesel. Advanced or second-generation biofuels, derived from non-food biomass like agricultural residues, waste, and dedicated energy crops, are also emerging but have not yet achieved large-scale production. However, expanding biofuel production using advanced feedstocks is essential to minimize impacts on land use, food and feed competition, and other environmental factors, while achieving a sharp increase in biofuel production. IEA foresees in their Net Zero scenario nearly a tripling of liquid biofuel production in 2030 compared to 2021 and they also foresee an enormous increase of advanced biofuel production, see Figure 8.

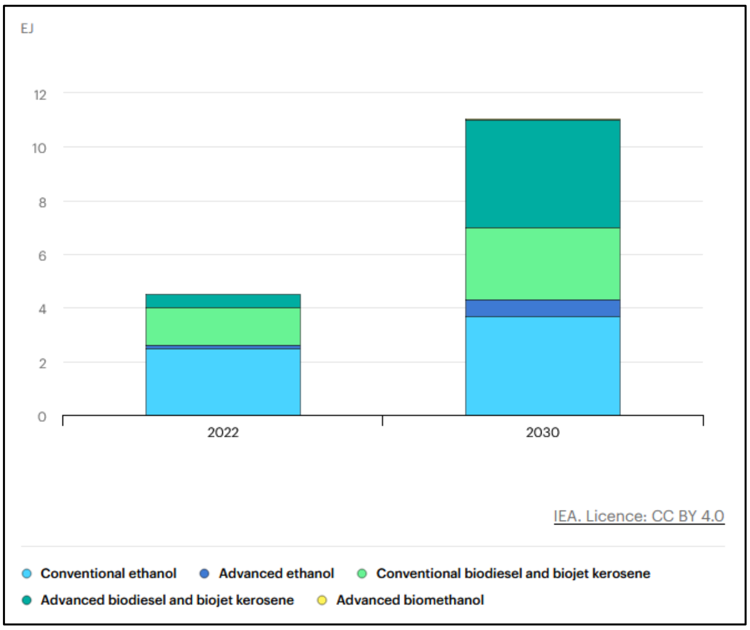


*Figure 8: Liquid biofuel production by feedstock and technology in Net Zero Scenario, 2022 and 2030 (IEA, 2023 b)*

Today, used cooking oil and waste animal fats are the most used non-food crop feedstocks for biofuel production. However, their limited availability highlights the need for the commercialization of new technologies to expand non-food crop biofuel production. Technologies such as cellulosic ethanol and biomass-based Fischer-Tropsch (bio-FT) can convert non-food feedstocks and residues into low-carbon biofuels for the transport sector. Therefore, all opportunities for producing alternative advanced biofuels should be looked at.

The need to increase biofuel production by 2030 is driven by the pressing requirements of the energy transition and global climate goals. Hard-to-electrify sectors, such as aviation, maritime transport, and heavy freight, require immediate low-carbon solutions that biofuels can provide. Increasing production by 2030 is critical to replace fossil fuels, reduce greenhouse gas emissions, and meet rising energy demand.

The recent developments we saw by assessing the demonstration plants and commercialization progress are listed and described in the following chapters.

## DATA SUMMARY

The current status of the IEA Bioenergy Task Database on facilities for the production of advanced liquid and gaseous biofuels for transport reflects the status on November 2024, where the last update has been finished.

The database comprised 258 active entries, related to the different technologies. The number of facilities per technology is listed in Table 3. The information in this database does not claim to be exhaustive or entirely accurate. Users are encouraged to cross-check information, as the content reflects the latest update but may omit recent developments or revisions.

*Table 3: Number of facilities per Technology listed in the Demoplants Database*

| Technology | Number of facilities | operational | Planned or under construction | Non operational, on hold, idle, cancelled |
|---|---|---|---|---|
| Alcohol-to-Jet | 10 | 2 | 8 | - |
| E-Fuels Biomass Hybrids | 20 | 2 | 11 | 7 |
| Fast pyrolysis | 23 | 16 | 3 | 4 |
| Fermentation | 71 | 46 | 15 | 10 |
| Gasification | 43 | 18 | 14 | 6 |
| Hydrothermal Liquefaction | 9 | 6 | 2 | 1 |
| Hydrotreatment | 78 | 41 | 32 | 5 |
| Others | 4 | 3 | - | 1 |
| **Sum** | **258** | **134** | **85** | **39** |

A detail list with the facilities, their location, status and capacity can be found in the Annex. There the facilities are listed according to the used technology.

## RECENT DEVELOPMENTS

By analyzing and monitoring the IEA Bioenergy Task 39 database on facilities for the production of advanced liquid and gaseous biofuels for transport over the years, important developments have become apparent in the following areas:


*Figure 9: Thematic areas with recent development*

### Technology development

**Main technologies** for the production of advanced **biofuels** include **cellulosic ethanol production**, which uses enzymes and microorganisms to break down lignocellulosic materials like agricultural residues, forestry waste, and dedicated energy crops into fermentable sugars. Another major technology is gasification followed by **Fischer-Tropsch (FT) synthesis**, a thermochemical process that converts biomass-derived syngas into liquid fuels, such as renewable diesel and jet fuel. **Pyrolysis** is also gaining traction, transforming organic materials and biomass into bio-oils, which can be upgraded into advanced fuels. Additionally, **hydrotreatment processes** are used to produce Hydrotreated Vegetable Oil (HVO) or

Hydroprocessed Esters and Fatty Acids (HEFA), leveraging feedstocks such as waste oils, fats, and greases to produce high-quality renewable diesel and sustainable aviation fuel.

The biofuel production pathway of producing hydrotreated vegetable and waste oil (HVO) renewable diesel and hydrotreated esters and fatty acids (HEFA) biojet kerosene from vegetable oils and waste oils has already achieved commercial status. Most of the operational advanced biofuel production facilities in the Task 39 demoplants database are using hydrotreatment as technology. The commercial viability of this technology is evident in its scalability and its ability to produce significant volumes of low-carbon fuels, which are in high demand to decarbonize transport sectors like aviation, shipping, and heavy-duty road transport

There is also a **diversification of technologies and combination of technologies** visible. In 2009 when the mapping of the advanced biofuel demonstration facilities started, the listed technologies were mainly fermentation to lignocellulosic ethanol and gasification with FT-liquid production and some hydrotreatment facilities were listed (Bacovsky et al., 2010 b). In the current status of the database there are more technologies listed using different feedstocks and synergies with other areas. Examples for this are co-processing, retro-fitting of oil refineries and hybrid systems with renewable hydrogen producing e-fuels.

**Co-processing** of biobased intermediates and biogenic feedstocks in existing petroleum refineries offers a cost-effective way to rapidly scale up the production of low-carbon-intensity (CI) fuels. This approach also plays a significant role in advancing the energy transition within the oil and gas sector. Biogenic feedstocks like lipids and oils or bio-oils from pyrolysis or biocrudes from hydrothermal liquefaction can be inserted into an existing petroleum refinery processing unit and is processed together with fossil feedstock. The product is then fuel with biogenic content. While coprocessing of lipids for renewable diesel and low-carbon jet fuel is already commercial, efforts are underway to expand to bio-oils and biocrudes from more abundant feedstocks like forest residues. Co-processing is gaining popularity and multiple fossil refineries are increasing their biogenic content in the product. Examples are co-processing of UCO in the OMV refinery in Austria, co-feeding of pyrolysis oil in the Petrobras pilot plant in Brazil and co-feeding of pyrolysis oil at the PREEM refinery in Sweden. More details on co-processing and the development can be found in the IEA Bioenergy Task 39 Report on Update on drop-in biofuel and co-processing commercialization(van Dyk et al., 2024).

Another option for decarbonizing is **retrofitting of existing oil refineries**. The refinery sector recognizes bioenergy retrofitting as an effective approach to increase the production of renewable transport fuels. The primary technology used for this purpose is hydroprocessing, which upgrades renewable liquid oils, such as palm oil and used cooking oil, into renewable transport fuels known as HVOs (Hydrotreated Vegetable Oils). Several refineries have already been retrofitted to produce HVOs, supporting the transition to greener biofuels. HVO production can be done in stand-alone facilities or retrofitted fossil refineries. Examples for companies which retrofitted their refineries are Marathon, PREEM, BP, Repsol, Cepsa, ENI, Total. More information on retrofitting can be found at the website of the Horizon Europe Project BioFIT Bioenergy Retrofits for Europe’s Industry.

In the last years when the topic of e-fuels and synthetic fuels came up, concepts were developed to use synergies between e-fuels and biofuels production in **e-fuel biomass hybrid systems.** Such systems produce low-carbon fuels through a combination of renewable electricity and biomass. There are different options of combinations: either $CO_2$ from a biofuel production process can be used as carbon source for e-fuel production or $H_2$ produced from electrolysis with renewable electricity can be used in a biofuel synthesis process to increase the amount of product. The first option can be seen as one possibility for BECCUS (Bioenergy with carbon capturing, utilizing and sequestration). Several biofuel production pathways inherently generate a nearly pure stream of $CO_2$ as part of their process, including ethanol fermentation (from both crop-based and cellulosic sources) and upgrading of biogas to biomethane. For e-fuel biomass hybrid most of the entries in our database are announcements and planned facilities (most of them in Europe), there are even already cancellations like the FlagshipOne project in Sweden. IEA Bioenergy has an inter-task project on deployment of BECCUS Value Chains, which analyses technological, political and economic aspects related to near- to medium term deployment of systems used for capture and utilization or storage of biogenic $CO_2$.

## Feedstock and Sustainability

**Feedstock availability** is a critical factor in the production of advanced biofuels, as it determines both the scalability and sustainability of fuel production. While oil-based residues, such as used cooking oil and animal fats, are valuable for current biofuel technologies, their limited supply poses a significant challenge to meeting future demand. To address this, biomass residues, including agricultural waste, forestry by-products, and other organic materials, present a promising alternative. These feedstocks are abundant, widely distributed, and often considered useless residues, making them both cost-effective and environmentally beneficial. Leveraging biomass residues through advanced technology pathways, such as cellulosic ethanol, hydrothermal liquefaction, and Fischer-Tropsch processes, can expand biofuel production capacity while reducing reliance on finite oil-based residues. To overcome feedstock limitations, it is important to diversify feedstocks and technology pathways, in particular for the rising demand of marine and sustainable aviation fuels.

In addition, non-biogenic waste streams are increasingly being used for the production of transport fuels. In the European context these fuels are called RFNBOs (renewable fuels of non-biological origin) and RCFs (recycled carbon fuels), while other major alternative fuel producing countries do not make such a distinction. RCFs are not taken into consideration in the Task 39 database, and for RFNBOs only the above-mentioned e-fuels biomass hybrids are listed. RFNBOs are synthetic fuels produced using renewable energy sources and non-biological raw materials, such as hydrogen derived from water electrolysis powered by renewable electricity, combined with captured carbon dioxide or nitrogen. These fuels include renewable hydrogen, e-methanol, e-diesel, and other e-fuels. RCFs are fuels produced from carbon-containing waste materials that would otherwise be discarded or emitted into the atmosphere. These include industrial waste gases, municipal solid waste, and other non-renewable sources of carbon.

The deployment of advanced biofuels will need different feedstocks like wastes, residues, forestry and energy crops and they need to be delivered sustainably. The feedstock should be produced in line with sustainable resource management, forestry and agricultural practice, with minimum impacts on land use change emissions. The sustainable feedstock availability is a major challenge and it is also a crucial topic to find consensus on sustainability criteria across the countries including social, economic and environmental benefits and GHG emission reductions. Appropriate land use planning can be a major element in assuring sustainability.

The European Union, through its Renewable Energy Directive, the United States, with the federal Renewable Fuel Standard Program and California's Low Carbon Fuel Standard (LCFS), and Brazil, via its RenovaBio program, have implemented frameworks to address certain aspects of biofuel sustainability. However, it is essential for other countries to adopt robust sustainability governance frameworks and align them with biofuel policy support to ensure global adherence to sustainable practices.

Nevertheless, there are **sustainability risks** regarding biofuels (deforestation, competition with food, indirect effects) which should be counteracted by worldwide agreements, the mentioned sustainability requirements and certification. IEA Bioenergy Task 39 deals with this topic as part of the project Improvement opportunities for policies and certification schemes promoting sustainable biofuels with low GHG emissions. The first part of the project has already been published and contained a review of policy frameworks (van Dam et al., 2022). The second part considers the **robustness of GHG emission certification** and verification – a case study of selected biofuel value chains and policies and will be soon available at the Task 39 website.

## Market and Deployment

The future markets for advanced biofuels lie predominantly in long-distance transport sectors such as **aviation, maritime shipping, and heavy-duty road transport**. These sectors face significant challenges in adopting electrification due to their high energy density requirements, long operational ranges, and lack of viable battery technologies. In contrast, road transport in passenger cars is rapidly transitioning to electrification, driven by advancements in battery technologies, decreasing costs, and supportive policies. Advanced biofuels, with their ability to deliver substantial greenhouse gas emission reductions and compatibility with existing engines and infrastructure, are well-suited to decarbonize the hard-to-electrify segments of the transport sector. By focusing on aviation, maritime, and heavy-duty transport, advanced biofuels can play a crucial role in achieving global climate targets while complementing electrification efforts in other areas.

IEA Bioenergy Task 39 already dealt with the topics of sustainable aviation fuels and maritime fuels in the last and current triennium; the topic of heavy-duty vehicles will be addressed in a project in the coming triennium.

A special focus lies on the renewable fuels and biofuels for the **aviation industry**, as the sector is continuously growing and needs all opportunities for reducing the carbon intensity. Mostly there are no dedicated SAF producing facilities, but facilities where part of the product can be SAF. According to the economic situation, the produced fraction of SAF can be increased. In the IEA Bioenergy Task 39 database more than 50 plants are listed which are capable of producing SAF, some of them are planned facilities, less than 20 are operational facilities. The main technology used is hydrotreatment and co-processing, but also the technologies ATJ (alcohol-to-jet), PtL (Power-to-Liquid) and gasification are used to produce SAF.

**SAF producing facilities in the Task 39 Demoplants Database**

The following list represents examples of planned and operational facilities with SAF production capacities:

BP (Spain), ENI (Italy), Neste (Finland, Netherlands, Singapore), Cepsa (Spain), Preem (Sweden), Repsol (Spain), Total (France), Eco Ceres (China), Sinopec (China), Revo (Japan), Cresta (US), Diamond Green Diesel (US), Lanzajet (US), Montana Renewables (US), Philipps 66 (US), ECB Group (Brazil), World Energy (US), Gevo (USA), …

A detailed analysis of the Progress in Commercialization of Biojet/Sustainable Aviation Fuels (SAF): Technologies and policies (van Dyk and Saddler, 2024) has been published recently by IEA Bioenergy Task 39. There trends and challenges of the different technology pathways are discussed and the essential role of policies for SAF development and commercialization is elaborated.

## Policy Frameworks

According to the International Energy Agency more than 80 countries worldwide have policies that support biofuel demand (IEA Biofuels, 2024). The different policies and jurisdictions are given in the Policies and Measures database (PAMS).

An in-depth analysis of the different biofuel policies of the IEA Bioenergy Task 39 member countries is give in the report Implementation Agendas: Compare-and-Contrast Transport Biofuels Policies (Mohammadi et al., 2023) This current issue (2023) updates the progress in biofuel production and use in member countries and the policies that have been used by Task 39 nations to promote low-carbon intensity (CI) biofuels. A key takeaway from the report is the need for effective biofuel policies to drive market growth. Mandates have proven successful in establishing and expanding biofuel markets, particularly for conventional biofuels like ethanol and biodiesel. However, policy efforts must increasingly focus on advanced "drop-in" biofuels, such as renewable diesel (HVO) and sustainable aviation fuels (SAF) are gaining traction in the market.

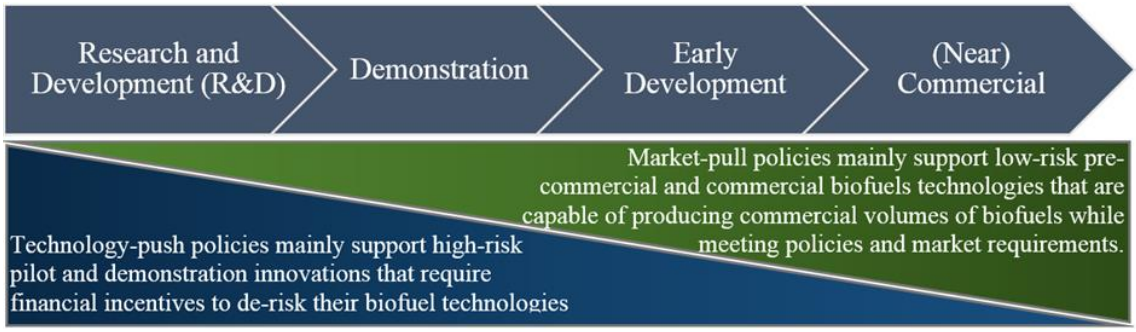


*Figure 10: Technology-push and market-pull biofuel policies from IEA AMF and IEA Bioenergy (IEA AMF and IEA Bioenergy, 2020)*

Policies play a crucial role in driving the growth of advanced biofuels, which are essential for decarbonizing transport, especially long-distance sectors. Key policy measures include blending mandates, GHG emission intensity reduction targets (also known as low-carbon fuel standards), tax reductions or exemptions, carbon pricing and various fiscal incentives and public financing mechanisms. These regulatory measures must be aligned with net zero targets to support investment. Countries that effectively combine market-pull and technology-push strategies have achieved the greatest success in scaling biofuel production, promoting their use, and advancing emerging biofuel technologies.

To date, most policies to promote transport decarbonization have primarily targeted road transport. In contrast, sectors like rail, aviation, and shipping, despite their significant energy consumption and greenhouse gas emissions, have historically received less policy focus. However, there is now a growing shift in transport policies and industry initiatives toward decarbonizing long-haul transport sectors, including road freight, rail, aviation, and shipping, where electrification poses greater challenges.

*Table 4: Policies with impact on advanced biofuel production for selected regions*

| Region | Policies and Legislation |
|---|---|
| EU | Renewable Energy Directive (RED)<br>ReFuel Aviation<br>FuelEU Maritime<br>EU-ETS (Emission Trading System) |
| USA and Canada | Inflation Reduction Act (IRA)<br>US Renewable Fuels Standard (RFS)<br>California Low Carbon Fuel Standard (LCFS)<br>Canadian Clean Fuel Standard (CFS) |
| Brazil | RenovaBio<br>Fuels of the Future Program |
| India | Roadmap for Ethanol Blending in India<br>National Policy on Biofuels |
| China | Action plan for carbon dioxide peaking before 2030<br>$14^{th}$ five year comprehensive work plan for energy conservation and emission reduction |
| International | Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) |

Research policy frameworks have played a pivotal role in driving the establishment of demonstration plants for advanced biofuel technologies, shaping investment decisions and the success or failure of these initiatives. Jurisdictions with robust supportive policies, such as Brazil, the USA, Europe, California, Germany, and Sweden, have been instrumental in fostering the development of demonstration projects across various technology pathways.

In the USA, federal programs like the Renewable Fuel Standard (RFS) and California's Low Carbon Fuel Standard (LCFS) have incentivized investments in advanced biofuel demonstration plants by setting ambitious renewable fuel mandates and rewarding low-carbon fuel production. These policies have encouraged the development of technologies such as cellulosic ethanol and renewable diesel. However, fluctuations in regulatory support, particularly delays or adjustments to RFS mandates, have also led to uncertainties, causing some plants to close or struggle financially.

In Europe, the Renewable Energy Directives (RED I and II) have been key in promoting the development of biofuel technologies, particularly advanced biofuels made from non-food feedstocks. Countries like Germany and Sweden have implemented additional national incentives, such as tax exemptions and funding for research and development, which have supported the construction and operation of demonstration plants. For example, Sweden's strong focus on renewable energy has led to the establishment of pioneering facilities exploring technologies like gasification and pyrolysis. However, inconsistent implementation of RED policies across member states has at times hindered progress.

Brazil, through its RenovaBio program, has focused on enhancing ethanol production from sugarcane and has begun promoting advanced biofuels, including cellulosic ethanol. The program provides strong regulatory incentives and carbon credit systems, which have attracted investments in innovative technologies and enabled Brazil to become a global leader in biofuels.

California's LCFS has proven particularly influential, offering credits for low-carbon fuel production and fostering the development of demonstration plants for renewable diesel and sustainable aviation fuel. This market-based policy has encouraged investment in facilities capable of reducing greenhouse gas emissions, positioning California as a hub for biofuel innovation.

However, not all initiatives have succeeded. Demonstration plants often face high capital costs and technical challenges, and closures have occurred where policy frameworks failed to provide long-term certainty or where market conditions made operations unsustainable. For example, policy gaps or insufficient incentives in some jurisdictions have limited investor confidence and stalled technology deployment.

Overall, jurisdictions with consistent, clear, and supportive research policy frameworks have seen the greatest success in establishing and scaling demonstration plants, driving innovation, and paving the way for the commercialization of advanced biofuels.

## Regional Aspects

In the IEA Bioenergy Task 39 database we see an increase in the amount of advanced biofuel production facilities in emerging economies like Brazil or China. Brazil is relying on agricultural residues from sugarcane production and China is increasingly utilizing exhaust and flue gases for the production of RCF. A relatively new announcement came for Brazil with Refinaria Riograndense in Rio Grande as first commercial-scale SAF production plant planned for 2028 with Topsoes hydrotreatment technology (Topsoe, 2024). In the IEA Renewables report from 2023 there is a huge predicted biofuel demand growth in emerging economies, where most of the demand comes from Brazil, followed by Indonesia and India (IEA, 2024 b).

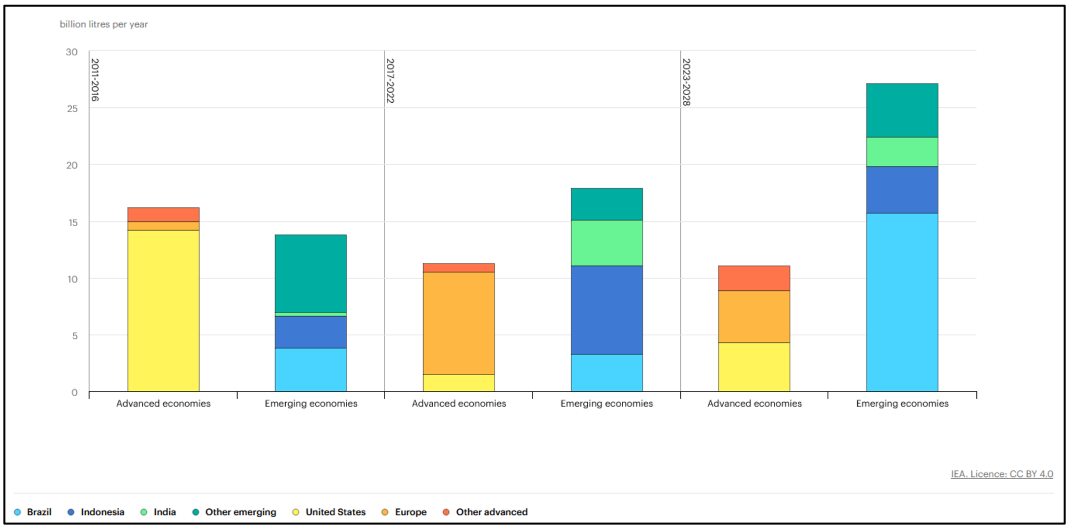


*Figure 11: Biofuel demand growth for advanced and emerging economies (IEA, 2024 b)*

The development of biofuels is gaining momentum in emerging economies due to their growing energy demand, abundant natural resources, and the need for sustainable development. Biofuels hold significant potential in emerging economies, offering a sustainable solution to meet growing energy demand while addressing environmental and socio-economic challenges. Many emerging economies, particularly those with abundant agricultural and forestry resources, are well-positioned to develop biofuel industries using locally available feedstocks like crop residues, sugarcane, palm oil, and waste materials. Biofuels offer a dual advantage for emerging economies: they enhance energy security by reducing reliance on expensive fossil fuel imports and support rural development by creating jobs and stimulating local economies.

Governments in emerging economies are increasingly implementing supportive policies and incentives, such as blending mandates and subsidies, to encourage biofuel production. For instance, countries like Brazil and India have established ambitious ethanol blending programs, while Southeast Asian nations are investing in biodiesel production from palm oil. Additionally, international collaboration and technology transfer are accelerating the deployment of advanced biofuel technologies, enabling these nations to produce biofuels more efficiently and sustainably.

The shift toward biofuels in emerging economies also reflects their commitment to addressing climate change and reducing greenhouse gas emissions. By developing domestic biofuel industries, these countries can contribute to global decarbonization efforts while reaping economic and environmental benefits. However, the expansion of biofuels must be carefully managed to avoid conflicts with food security, land use, and biodiversity.

IEA Bioenergy Task 39 reflects on the developments in emerging economies in several reports: Biofuels in Emerging Markets - Potential for sustainable production and consumption from 2023 (Mendes Souza et al., 2023) and Biofuels in Emerging Markets of Africa and Asia - An overview of costs and greenhouse gas savings from 2024 (Leal Silva et al., 2024).

## Demonstration and Commercialization

Decarbonization targets demand large amounts of biofuel and volumes and production capacity needs to be increased. In recent years, there has been a huge increase in the number of announcements for the construction of new production facilities, in particular for the well-established HVO producing technology and for dedicated SAF facilities. The rising number of planned plants is due to the increasing demand for liquid biofuels and the fulfilment of targets. But not all announcements are leading to operational production plants. Also, the numbers of cancelations and postponements of start-up dates are increasing.

*Table 5: Examples for closed facilities and cancelations of announcements*

| Company | Location | Technology | Status |
|---|---|---|---|
| Clariant | Podari Romania | Fermentation to Cellulosic Ethanol | 2021-2023 |
| DuPont | Nevada, US | Fermentation to Cellulosic Ethanol | 2014-2017 |
| Abengoa | Hugoton, US | Fermentation to Cellulosic Ethanol | 2014-2015 |
| POET DSM | Emmetsburg, US | Fermentation to Cellulosic Ethanol | 2014-2019 |
| Beta Renewables | US, China | Fermentation to Cellulosic Ethanol | cancelled |
| Ineos Bio | UK | Fermentation to Cellulosic Ethanol | cancelled |
| Fulcrum Bioenergy | Centerpoint, US | Gasification and FT-Synthesis | cancelled |
| Gobigas | Gothenburg, Sweden | Gasification and FT-Synthesis | cancelled |
| Red Rock Biofuels | Lakeview, US | Gasification and FT-Synthesis | Never been opened |
| Shell | Rotterdam, Netherlands | Hydrotreatment | Paused |
| Liquid Wind / Orsted | Flagship Series, EU | E-Fuels Biomass | Cancelled |

The commercialization progresses for some technologies, f.e. the hydrotreatment technology is now available on commercial scale. But for other technologies, in particular for cellulosic ethanol, the commercialization progresses generally slow, with failures that set back the whole industry and situation. We have seen that commercialization takes time, from the first announcement and plans for an advanced biofuels production facility, to the financial investment decision, the construction phase up to the production of the transport fuel. Nevertheless, the scale-up steps should not be done too fast, as this might lead to renewed failures.

**Cellulosic Ethanol worldwide capacity development**

The commercialization of cellulosic ethanol has not gained the anticipated momentum. In a scientific publication planned for 2025, we aim to examine this development and analyse it using insights from the IEA Bioenergy Task 39 database. The analysis is based on yearly excerpts from the database from 2009 up to the present year.

There has been a positive development and drive in cellulosic ethanol production which was then followed by cancelled and failed projects. The predicted capacities were not reached and the hoped breakthrough has not been achieved because the three largest plants from 2015 were closed.

In recent years there are promising developments and an increase in capacity in emerging economies like Brazil.

Many biofuel production pathways have reached commercial status, including ethanol from corn and sugarcane, FAME biodiesel, HVO renewable diesel, and HEFA biojet kerosene from vegetable and waste oils. Others, like the alcohol-to-jet (ATJ) pathway from ethanol, are nearing commercialization. Innovations such as novel oilseed crops and advanced technologies for converting woody and grassy biomass (e.g., agricultural and forestry residues) are also progressing.

Thermochemical routes like biomass gasification followed by Fischer-Tropsch (bio-FT) synthesis, hydrothermal liquefaction, and fast pyrolysis with upgrading offer pathways to scale renewable diesel and biojet production sustainably. Bio-FT is advancing, with several commercial-scale projects underway, primarily in the U.S., Europe, and Japan, using diverse feedstocks like forestry residues and municipal solid waste. Some projects try to integrate carbon capture and storage to achieve negative emissions. Hydrothermal liquefaction and fast pyrolysis with upgrading are less advanced, facing challenges in bio-oil pre-treatment for hydroprocessing. However, bio-oils can be co-processed with petroleum products in existing refineries, reducing capital costs.

Global transport biofuel capacity grew by 7% in 2022, marking the largest annual increase in over a decade. This expansion was driven primarily by renewable diesel production, supported by favorable policies in the United States and Europe. Ethanol capacity also saw significant growth in Brazil, Indonesia, India, and China (IEA Biofuels, 2024). Although the biofuel investments and capacity building reached the highest values in 2022, annual investment needs to increase further to get on track with the NZE Scenario.

While there are numerous announcements, the actual production capacities are not growing at the pace needed to achieve climate-relevant targets. According to the IEA analysis tracking clean energy progress from 2023 (IEA, 2023 a), biofuels are off track to fulfill the requirements for the Net Zero Emissions by 2050 (NZE) scenario. Biofuel demand reached a record high of 4.3 EJ (170,000 million liters) in 2022, surpassing pre-COVID-19 levels from 2019. However, to align with the Net Zero Emissions by 2050 (NZE) Scenario and achieve the necessary emission reductions, biofuel production must increase significantly, reaching over 10 EJ by 2030. This requires an average annual growth rate of approximately 11%. Additionally, the use of advanced feedstocks must expand substantially, with biofuels derived from waste, residues, and non-food energy crops projected to supply over 40% of total demand by 2030, up from just 9% in 2021. The NZE Scenario requires the expansion of both waste- and residue-based fuels and fuels with lower GHG emissions that use technologies such as carbon capture and storage.

## IMPORTANCE OF SCALE-UP AND DEMONSTRATION

The following insights are derived from our extensive work with the IEA Bioenergy Task 39 Demoplants database.

Advanced biofuels are essential for reducing greenhouse gas emissions and achieving global climate goals. They play a crucial role in providing low-carbon energy solutions, particularly for hard-to-abate sectors such as aviation, maritime shipping, and heavy-duty transport. These biofuels are integral to creating a sustainable energy future, as they reduce reliance on fossil fuels and help bridge the gap between current energy needs and renewable energy targets.

It is of greatest importance to stimulate development and deployment of new technologies. Innovative and new technologies are needed to reach the targets for biofuel demand in the future scenarios.Despite their potential, advanced biofuel technologies are not yet fully developed or commercially viable on a large scale.

The scale-up and demonstration of advanced biofuel technologies are critical steps in transitioning from laboratory innovation to commercial viability, enabling these technologies to contribute meaningfully to global energy needs and climate goals. Demonstration plants serve as a bridge between research and full-scale production, allowing for the validation of processes, optimization of technology, and identification of economic and operational challenges under real-world conditions.

Demonstration of technologies lead to improvements and benefits:

- Cost Reduction:
  One of the primary reasons for scaling-up advanced biofuel technologies is to reduce costs through economies of scale and process improvements. Many advanced biofuels, such as cellulosic ethanol, Fischer-Tropsch fuels, and renewable diesel, currently face high production costs compared to fossil fuels. Demonstration facilities allow developers to refine production techniques, improve efficiency, and lower costs, making these fuels more competitive in the marketplace.
- Investment Attraction:
  Demonstration plants are also essential for attracting investment and building confidence among stakeholders, including governments, private investors, and end-users. By proving the technical and economic feasibility of advanced biofuels at a larger scale, these projects can secure the funding and policy support needed to transition to commercial-scale production.

- Supply Chain Insights:
  The scale-up process also plays a vital role in addressing logistical and supply chain challenges. For example, demonstration plants provide insights into feedstock availability, transportation logistics, and integration with existing infrastructure. Feedstock supply chains can be proven. These insights are crucial for ensuring a reliable and sustainable feedstock supply while minimizing environmental impacts, such as land-use changes.
- Technical Challenges:
  Additionally, demonstration plants help identify and address unforeseen technical and operational challenges that may not emerge during small-scale research and development. These include issues related to equipment performance, process scalability, and compliance with environmental standards. Overcoming these hurdles at the demonstration stage helps de-risk the technology, making it more attractive for commercial deployment.
- Sustainability Metrics:
  Policymakers can assess environmental and economic benefits, enabling the creation of supportive regulatory frameworks.
- Increasing production volumes
  Ultimately, scaling-up and demonstrating advanced biofuel technologies are crucial for achieving the significant production volumes required to meet global decarbonization targets, particularly in hard-to-abate sectors like aviation, shipping, and heavy-duty transport. Without these intermediate steps, the full potential of advanced biofuels to contribute to a sustainable energy future cannot be realized.

Scaling up advanced biofuel production remains a global challenge, requiring significant efforts in environmental, social, and economic sustainability. The process involves overcoming high production costs, technological complexities, and feedstock supply constraints.

Reaching commercialization is critical: this process takes time, starting from first plans or announcements of facilities to operation and production of advanced transport fuels. Within this process the risk of scaling-up too fast is given. Setbacks can then set back the entire industry and the commercialization process.

The following points are enablers and accelerators for successful scale-up:

- Policy Frameworks: implementation of life-cycle carbon intensity-based policy frameworks for transport solutions, which can incentivize the adoption of low-carbon technologies.
- Financial Support: financial de-risking measures should be introduced to attract private sector participation.
- Government Support: Enhance municipal planning, waste management, and public procurement efforts.
- Sustainability Governance: Ensure robust sustainability standards to gain public and policymaker trust.
- Infrastructure and Skills: Develop infrastructure, establish technical standards, and invest in workforce training to support deployment.

Demonstration and scale-up efforts are critical for advancing biofuel commercialization and realizing their full potential to address climate goals. Scaling production now provides the necessary time for technology maturation and ensures a diversified, sustainable energy system. However, commercialization requires careful planning to avoid setbacks that could hinder progress for the entire industry.

The economic viability and scalability of some biofuels, as well as their competitiveness with fossil fuels, remain problematic. Research, policy support, and global cooperation are crucial to maximizing the potential of biofuels in achieving sustainable transport and long-term environmental goals.

## IMPLEMENTATION BARRIERS AND OPPORTUNITIES

The following insights are derived from our extensive work with the IEA Bioenergy Task 39 Demoplants database.

Despite their potential to significantly reduce greenhouse gas emissions and provide sustainable alternatives to fossil fuels, the implementation of advanced biofuels faces several barriers. High production costs, technological complexity, and limited availability of suitable feedstocks remain key challenges. Market uncertainties and insufficient policy support further hinder large-scale adoption, while competition with conventional fuels and other renewable energy sources adds pressure. Current market conditions reveal a clear lack of investment in large-scale demonstration facilities for advanced biofuel production, posing a significant barrier to further technological development and deployment.

Additionally, the need for robust sustainability governance and concerns about land use, biodiversity, and food security complicate public acceptance. Addressing these barriers through targeted investments, policy frameworks, and technological innovation is critical to unlocking the full potential of advanced biofuels in decarbonizing the transport sector.

The economic viability and scalability of certain biofuels, as well as their competitiveness with fossil fuels, remain significant challenges. These include relatively low oil prices, slower than expected progress in the commercialization of ‘conventional/advanced’ biofuels, the availability, cost and sustainability of feedstocks, continued uncertainty about future biofuel policy, the almost always higher cost of biofuels and the lack of ‘carbon pricing’ for fossil fuels. Research, political support, and global collaboration are essential to maximizing the potential of biofuels in achieving sustainable transportation and long-term environmental goals.

The main implementation barriers are summarized in the following listing:

- High production **costs** of advanced biofuel
- **Financial risks** of demonstration and First-of-its-kind facility
- Uncertainty of regulatory framework and **policies**
- Availability and sustainability of **Feedstock**
- **Policy focus** on other options

Biofuels offer numerous advantages and versatile applications. Fuels from biomass and biogenic wastes have a unique role, as they are available now and can be implemented and integrated with existing infrastructure. Biofuels can be used in the different transport modes and sectors, in particular they are advantageous for the long-distance transport with their high energy density. Liquid biofuels are storable and can support expansion of other renewables. Combined with carbon capture and storage biofuels can reduce emissions further.

Advanced biofuels present significant opportunities to transform the energy landscape and contribute to global climate goals. With their ability to utilize non-food feedstocks such as agricultural residues, forest biomass, and waste materials, advanced biofuels can expand the range of sustainable energy sources while reducing reliance on fossil fuels. These fuels are particularly well-suited for hard-to-decarbonize sectors like aviation, maritime, and heavy-duty transport, where electrification faces technical and economic barriers. In these sectors, biofuels are the most viable option due to their high energy density and inherent properties. Furthermore, the development and deployment of advanced biofuel technologies can drive innovation, create green jobs, and support rural economies. By fostering energy security and reducing greenhouse gas emissions, advanced biofuels offer a viable pathway toward a cleaner, more sustainable future.

The main opportunities are summarized in the following listing:

- Based on broad variety of biomass feedstocks - **diversification of energy supply**
- Biomass production provides **regional income**
- Applicable in current vehicles now - offer **immediate GHG emission reductions**
- **High energy density** - alternative solution for sectors that are **hard-to-electrify**
- Defossilization of Long-Distance Transport: Aviation - Heavy Duty - Marine

## Outlook for Demonstration of Advanced Biofuels Production

Advanced biofuels hold immense potential to contribute to sustainable transportation by reducing reliance on fossil fuels and cutting greenhouse gas emissions. The market share of biofuels will increase inthe transportation sector in the coming years, if supported through appropriate measures to establish production infrastructure and policy-driven markets. In the long term, deployment of advanced biofuels at scale can lower production costs, making biofuels economically competitive.

However, renewable fuels, including biofuels, currently account for only about 6% of global transport energy demand (IEA, 2024 c). This share is expected to grow significantly, especially in sectors that are challenging to electrify, such as aviation and marine transport. Also, biofuel use is expected to expand rapidly and remain a dominant alternative to fossil fuels in regions like Brazil, India, and Indonesia. To meet the projected needs of 2050, production capacity must increase five- to tenfold, necessitating significant advancements in technology and market readiness, especially for more complex and cost-intensive renewable fuel options.

The production of biofuels also offers considerable social and economic benefits at local, regional, and national levels. Sustainable biofuel development can create jobs, particularly in rural and agriculture-based areas, by promoting feedstock cultivation and conversion. Increased demand for feedstocks can reduce surplus crops and the need for farming subsidies, while processing facilities provide employment opportunities and foster economic development in both industrialized and non-industrialized regions.

Decarbonizing transport, especially in aviation, maritime, and long-distance trucking, is an urgent priority. Biofuels and other renewable fuels will play an essential role in achieving this, with a tenfold increase in renewable fuel production required by 2050.

Commercialization of diverse technologies and feedstocks is necessary to meet this demand, emphasizing regional differences and involving existing refinery companies to achieve scalability. Retrofitting traditional refineries for oil-based biofuels has already begun, but further technical challenges and the cost gap between biofuels and conventional fuels persist. Enabling policies, including consistent standards for determining carbon intensity, will be vital to drive the development of low-carbon-intensity biofuels globally.

*Table 6: Main conclusions on the future outlook for advanced biofuels*

| **Key messages** | **Biofuels and advanced biofuels play an important role in decarbonizing the transport sector** |
|---|---|
| Advantages of advanced biofuels | Advanced biofuels pose many advantages like the variety of technologies and feedstocks/residues that can be used, the possible integration in existing fleets and infrastructure and their high energy density and storability. |
| Need for Commercialization | For commercialization of advanced biofuels the demonstration and scale-up, as well as building up capacity and production volumes are necessary. The reduction of costs and financial risks is essential and long-term policies and comprehensive strategies are needed to lead the way to commercialization. |
| Promising opportunities and developments | The promising opportunities and positive developments for advanced biofuels are the increasing demand and production in emerging economies and the defossilization in long-distance transport, like in the aviation, maritime and heavy-duty sector. |

## List of Figures



## List of Tables

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# Appendix - List of Facilities

This is an excerpt is from the IEA Bioenergy Task 39 Demoplants database. The database was last updated in November 2024, and the excerpt was generated on November 25, 2024. At that time, the database comprised 258 active entries.

This database/listing does not claim to be complete or entirely accurate. Users should verify details independently, as the information reflects the state of knowledge at the time of the last update and may not include recent changes.

The entries are organized here by technology. The technologies listed are Alcohol-to-Jet, E-Fuels Biomass Hybrids, Fast Pyrolysis, Fermentation, Gasification, Hydrothermal Liquefaction, Hydrotreatment and others.

*Table 7: List of Alcohol-to-Jet Facilities*

| Company | Location | Country | Status | Startup | Product | Capacity | Unit |
|---|---|---|---|---|---|---|---|
| Gevo | Silsbee | United States | operational | 2026 | SAF | 200 | t/y |
| LanzaJet | Soperton | United States | operational | 2024 | SAF<br>RD (HVO) | 27000<br>3000 | t/y<br>t/y |
| Gevo | Lake Preston | United States | planned | 2026 | SAF<br>Renewable naphta | 180000 | t/y |
| Consortium: Biomaterial in Tokyo(bits), Sanyu Plant Service | Shikokuchuo-shi | Japan | planned | 2025 | Ethanol<br>SAF<br>Renewable naphta | n.a. | t/y |
| Swedish Biofuels AB | Brista | Sweden | planned | 2025 | SAF | 20000 | t/y |
| LanzaTech UK | Port Talbot | United Kingdom | planned | 2026 | SAF | 79000 | t/y |
| HCS Group | Speyer | Germany | planned | 2026 | SAF | 60000 | t/y |
| Avina Clean Hydrogen | | United States | planned | 2027 | SAF | 350000 | t/y |
| Idemitsu | Ichihara-shi | Japan | under construction | 2027 | SAF<br>RD (HVO)<br>Renewable naphtha | 78000 | t/y |
| Consortium: Cosmo Oil, Mitsui | | Japan | planned | 2028 | SAF | 170000 | t/y |

*Table 8: List of E-Fuels Biomass Hybrid Facilities*

| Company | Location | Country | Status | Startup | Product | Capacity | Unit |
|---|---|---|---|---|---|---|---|
| STORE&GO Projektpartner | Pritzwalk | Germany | no status | 2018 | SNG | 323 | t/y |
| EXYTRON GmbH | Rostock | Germany | non operational | 2015 | SNG | n.a. | t/y |
| sunfire GmbH | Dresden | Germany | non operational | 2014 | FT liquids | 44 | t/y |
| Technical University of Munich | Straubing | Germany | non operational | 2021 | other | 1 | t/y |
| Liquid Wind / Orsted | Ornskoldsvik | Sweden | on hold | 2025 | methanol | 50000 | t/y |
| Synkero | Amsterdam | Netherlands | planned | 2027 | SAF | 50000 | t/y |
| Consortium: Toshiba, TOYO, Idemitsu, Japan CCS, ANA, Toshiba Energy Systems | Kawasaki-shi | Japan | operational | 2024 | SAF | n.a. | t/y |
| Perstorp | Stenungsund | Sweden | planned | 2025 | methanol | 200000 | t/y |
| Vattenfall | Forsmark | Sweden | planned | 2030 | SAF | 80000 | t/y |
| Uniper | Langsele | Sweden | planned | 2028 | SAF | 100000 | t/y |
| Elyse Energy | Pardies | France | planned | 2028 | SAF<br>renewable naphta | 75000<br>35000 | t/y<br>t/y |
| SSE Suomen Säätöenergia and Andritz | Nurmes | Finland | planned | 2026 | methanol | n.a. | t/y |
| Liquid Wind / Sundsvall Energi | Sundsvall | Sweden | on hold | 2026 | methanol | 130000 | t/y |
| Power2X | Pärnu | Estonia | planned | 2028 | methanol | 500000 | t/y |
| Liquid Wind / Umea Energi | Umea | Sweden | on hold | 2027 | methanol | 130000 | t/y |
| Solarig | Soria | Spain | planned | | SAF | 60000 | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Simply Blue Group | | Ireland | planned | | SAF methanol | 300000 | t/y |
| Simply Blue Group | | Canada | planned | 2026 | SAF methanol | 300000 | t/y |
| Simply Blue Group | | Australia | planned | | SAF methanol | 300000 | t/y |
| Nexxoil GmbH | Hamburg | Germany | operational | 2023 | bio-oil | 100 | t/y |

*Table 9: List of Fast Pyrolysis Facilities*

| **Company** | **Location** | **Country** | **Status** | **Startup** | **Product** | **Capacity** | **Unit** |
|---|---|---|---|---|---|---|---|
| Groupe Onym | | Canada | under construction | | pyrolysis oil<br>clean syngas | 6000 | m3/y |
| BTG-BTL | Hengelo | Netherlands | operational | 2015 | pyrolysis oil<br>steam<br>power | 24000 | t/y |
| Ensyn, Arbec Forest Products and Rémabec | Quebec | Canada | operational | 2018 | gasoline-type fuels | 36000 | t/y |
| Rottneros | Vallvik | Sweden | cancelled | | methanol | 140000 | t/y |
| BTG-BtL | | Netherlands | operational | 1998 | pyrolysis oil | 1000 | t/y |
| Twence | Enschede | Netherlands | operational | 2015 | pyrolysis oil<br>steam<br>power | 24000<br>8<br>0.7er | t/y<br>MW<br>MWel |
| Shell | Bangalore | India | no status | 2019 | pyrolysis oil | 0.1 | t/y |
| G4 Insight | | United States | operational | 2015 | SNG | 0.1 | t/y |
| G4 Insight | | Canada | operational | 2018 | SNG | 0.1 | t/y |
| Pyrocell (JV of Setra and Preem) | Gavle | Sweden | operational | 2021 | pyrolysis oil | 24000 | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Biozin | Amli | Norway | on hold | | pyrolysis oil | 100000 | t/y |
| Green Fuel Nordic | Lieksa | Finland | operational | 2020 | pyrolysis oil | 24000 | t/y |
| Shanxi Yingjiliang Biomass Company and Shanghai Jiao Tong University | Dali County | China | operational | | bio-oil | 4500 | m3/y |
| MASH ENERGY | Ahmedabad | India | operational | | pyrolysis oil | 1 | t/y |
| ALTACA ENERGY | Gönen | Turkey | operational | | bio-oil | 20000 | m3/y |
| Karlsruhe Institute of Technology (KIT) | Eggenstein-Leopoldshafen | Germany | operational | 2010 | bio-oil<br>solid fuels | n.a. | t/y |
| DTU Chemical engineering | Roskilde | Denmark | non operational | 2002 | clean syngas<br>bio-oil<br>solid fuels | n.a. | t/y |
| AquaGreen ApS | Roskilde | Denmark | operational | | clean syngas<br>solid fuels | n.a. | t/y |
| AquaGreen ApS | Farevejle | Denmark | operational | 2022 | clean syngas<br>solid fuels | n.a. | t/y |
| Stiesdal SkyClean A/S | Skive | Denmark | operational | 2022 | clean syngas | n.a. | t/y |
| Fraunhofer Umsicht | Hohenburg | Germany | operational | 2021 | bio-oil<br>solid fuels<br>clean syngas | 450<br>2000<br>780 | t/y<br>t/y<br>t/y |
| Stiesdal SkyClean A/S | Vrå | Denmark | under construction | 2024 | Heat<br>solid fuels | 20<br>14000 | MW<br>t/y |
| Frichs Pyrolysis ApS | Horsens | Denmark | under construction | 2024 | clean syngas<br>solid fuels | 2 | MW |

*Table 10: List of Fermentation Facilities*

| Company | Location | Country | Status | Startup | Product | Capacity | Unit |
|---|---|---|---|---|---|---|---|
| Iogen Corporation | Ottawa | Canada | no status | 2004 | ethanol | 1600 | t/y |
| POET-DSM Advanced Biofuels | Emmetsburg | United States | idle | 2014 | Ethanol FT-liquids biogas | 75000 | t/y |
| Iowa State University | Boone | United States | operational | 2009 | Ethanol FT-Liquids | 200 | t/y |
| Queensland University of Technology | Mackay | Australia | operational | 2010 | Ethanol lignin chemicals | n.a. | t/y |
| POET | Scotland | United States | operational | 2008 | ethanol | 60 | t/y |
| BioGasol | Aakirkeby, Bornholm | Denmark | cancelled | 2013 | Ethanol biogas lignin | 4000 | t/y |
| Sekab Group | Ornskoldsvik | Sweden | operational | 2004 | ethanol | 160 | t/y |
| Procethol 2G | Pomacle | France | operational | 2011 | ethanol | 80 | t/y |
| AustroCel Hallein | Hallein | Austria | operational | 2020 | ethanol | 30000 | t/y |
| Borregaard Industries AS | Sarpsborg | Norway | operational | 1938 | ethanol | 15800 | t/y |
| Borregaard AS | Sarpsborg | Norway | operational | 2012 | Ethanol lignin chemicals | 110<br>110 | t/y<br>t/y |
| Chempolis Ltd. | Oulu | Finland | operational | 2008 | Ethanol chemicals | 5000 | t/y |
| Clariant | Straubing | Germany | non operational | 2012 | ethanol | 1000 | t/y |
| GranBio | Sao Miguel | Brazil | operational | 2014 | ethanol | 65000 | t/y |
| NREL (National Renewable Energy Laboratory) | Golden | United States | operational | 2011 | ethanol | 100 | t/y |
| Longlive Bio-technology Co. | Yucheng | China | operational | 2012 | ethanol | 60000 | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ltd. | | | | | | | |
| Raizen Energia | Costa Pinto | Brazil | operational | 2015 | ethanol | 50000 | t/y |
| St1 | Kajaani | Finland | idle | 2017 | ethanol | 8000 | t/y |
| Domsjoe Fabriker | Ornskoldsvik | Sweden | operational | 1940 | ethanol | 19000 | t/y |
| Greenfield Ethanol | Chatham, ON | Canada | operational | 2010 | ethanol | 30 | t/y |
| BP Biofuels | Highlands County, FL | United States | cancelled | | ethanol | 108225 | t/y |
| Verbio | Nevada | United States | operational | 2022 | biogas | 20 | MW |
| Anhui BBCA Biochemical | Bengbu | China | operational | 2003 | ethanol | 5000 | t/y |
| Henan Tianguan Group | Zhenping | China | operational | 2009 | ethanol | 20000 | t/y |
| Jilin Fuel Alcohol | Jilin | China | operational | 2006 | ethanol | 1000000 | t/y |
| Shandong Zesheng Biotech Co. | Tai'an | China | operational | 2006 | ethanol | 3000 | t/y |
| Energy & Chemical Department of East China University of Science and Technology | Shanghai | China | operational | 2005 | ethanol | 600 | t/y |
| COFCO Zhaodong Co. | | China | operational | 2006 | ethanol | 500 | t/y |
| Henan Tianguan Group | Nanyang | China | operational | 2011 | ethanol | 30000 | t/y |
| Versalis / Eni | Crescentino | Italy | operational | 2013 | ethanol | 25000 | t/y |
| GranBio Technologies | Thomaston | United States | operational | 2015 | ethanol | 180 | t/y |
| ArcelorMittal | Ghent | Belgium | operational | 2022 | ethanol | 64000 | t/y |
| Shougang LanzaTech | Caofeidian | China | operational | 2018 | ethanol | 46000 | t/y |
| Clariant | Podari | Romania | non | 2021 | ethanol | 50000 | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | operational | | | | |
| Indian Oil Corporation | Panipat | India | operational | 2022 | ethanol | 27000 | t/y |
| Global Bioenergies | Leuna | Germany | non operational | 2017 | isobutene | 100 | t/y |
| Consortium: Sekisui Chemical, Sekisui Bio Refinery, Innovation Network Corporation of Japan(INCJ) | Kuji-shi | Japan | operational | 2022 | ethanol | 17 | t/y |
| Anhui Guozhen Group and Chemtex Chemical Engineering | Fuyang | China | cancelled | 2020 | ethanol | 50000 | t/y |
| Kanteleen Voima | Haapavesi | Finland | planned | 2027 | Ethanol<br>biogas<br>lignin | 65000<br>30<br>230000 | t/y<br>MW<br>t/y |
| St1 | Vantaa | Finland | idle | 2009 | ethanol | 1000 | t/y |
| St1 | Lahti | Finland | idle | 2009 | ethanol | 1000 | t/y |
| IBN-One (JV of Cristal Union and Global Bioenergies) | Pomacle | France | operational | 2022 | isobutene | 50000 | t/y |
| Indian Oil Corporation | Panipat | India | under construction | 2022 | ethanol | 31000 | t/y |
| Indian Oil Corporation | Panipat | India | under construction | 2022 | ethanol | 700 | t/y |
| Indian Oil R&D | Faridabad | India | operational | 2012 | ethanol | 16 | t/y |
| Indian Glycol & DBT-ICT Mumbai | Kashipur | India | operational | 2016 | ethanol | 700 | t/y |
| Praj Industries | Pune | India | operational | 2017 | ethanol | 850 | t/y |
| Assam Bio Ethanol Ltd | Numaligarh | India | under construction | | ethanol | 50000 | t/y |
| Hindustan | Bargarh | India | under | 2022 | ethanol | 29000 | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Petroleum | | | construction | | | | |
| Bharat Petroleum | Bhatinda | India | under construction | 2022 | ethanol | 29000 | t/y |
| DINS Sakai Co.,Ltd. | Sakai-shi | Japan | operational | 2007 | ethanol | 1100 | t/y |
| RYAM Rayonier Advanced Materials Inc. | Tartas | France | planned | | ethanol | 17000 | t/y |
| NACRE | Lacq | France | planned | | ethanol | 30000 | t/y |
| COFCO | Hefei | China | operational | 2020 | ethanol | 700000 | t/y |
| New Tianlong Wine Industry | Jixi | China | operational | 2011 | ethanol | 10000 | t/y |
| Inner Mongolia Lisheng Bio-refining Co. and Inner Mongolia Zhongneng Biotechnology Co. | Bayannaoer | China | operational | 2019 | ethanol | 150000 | t/y |
| Yigao Bioenergy Co. | Cangzhou | China | operational | 2021 | ethanol | 25000 | t/y |
| Hongzhan Group | Harbin | China | operational | 2019 | ethanol | 300000 | t/y |
| SDIC Biotech GROUP | Jixi | China | operational | 2018 | ethanol | 300000 | t/y |
| Wanlilida Group and Heilongjiang Wanlilida Co. | | China | operational | 2017 | ethanol | 300000 | t/y |
| SDIC Biotech Group and SDIC Bioenergy Hailun Co. | Hailun | China | operational | 2018 | ethanol | 300000 | t/y |
| SDIC Biotech Group and SDIC Bioenergy Bei'an Co. | Bei'an | China | operational | 2018 | ethanol | 300000 | t/y |
| Raizen Energia | Guariba | Brazil | operational | 2024 | ethanol | 62000 | t/y |
| Raizen Energia | Barra Bonita | Brazil | under construction | 2025 | ethanol | 62000 | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Raizen Energia | Valparaíso | Brazil | under construction | 2025 | ethanol | 62000 | t/y |
| Raizen Energia | Andradina | Brazil | under construction | 2027 | ethanol | 62000 | t/y |
| Raizen Energia | Morro Agudo | Brazil | under construction | 2027 | ethanol | 62000 | t/y |
| Raizen Energia | Taruma | Brazil | under construction | 2027 | ethanol | 62000 | t/y |
| Raizen Energia | Sertaozinho | Brazil | planned | | ethanol | 62000 | t/y |
| Raizen Energia | Caarapo | Brazil | planned | | ethanol | 62000 | t/y |
| Meliora Bio AsP | Kalundborg | Denmark | operational | 2022 | ethanol | 5000 | t/y |

*Table 11: List of Gasification Facilities*

| Company | Location | Country | Status | Startup | Product | Capacity | Unit |
|---|---|---|---|---|---|---|---|
| CHOREN Industries GmbH | Schwedt | Germany | cancelled | | FT liquids | 200000 | t/y |
| CHOREN Fuel Freiberg GmbH & Co. KG | Freiberg | Germany | cancelled | | FT liquids | 13500 | t/y |
| Bio SNG Guessing | Güssing | Austria | idle | 2008 | SNG | 576 | t/y |
| ECN | Petten | Netherlands | operational | 2009 | clean syngas | 200 | m3/h |
| Enerkem | Montreal | Canada | operational | 2003 | Ethanol<br>methanol<br>SNG | 375<br>475 | t/y<br>m3/y |
| GTI Gas Technology Institute | Des Plaines | United States | operational | | Heat<br>gasoline-type fuels | 5<br>38 | MWth<br>m3/y |
| Tembec Chemical Group | Temiscaming | Canada | operational | | ethanol | 13000 | t/y |
| West Biofuels | Woodland, CA | United States | operational | 2007 | FT liquids | n.a. | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| E.ON Gasification Development AB | Scania | Sweden | cancelled | | SNG<br>heat | 200<br>50 | MW<br>MWth |
| Enerkem Alberta Biofuels LP | Edmonton | Canada | non operational | 2014 | Ethanol<br>methanol<br>chemicals | 30000 | t/y |
| Enerkem | Westbury | Canada | operational | 2009 | Ethanol<br>methanol<br>chemicals | 4000 | t/y |
| Thermochem Recovery International | Durham | United States | operational | 2007 | FT liquids<br>mixed alcohols<br>power | n.a. | t/y |
| Karlsruhe Institute of Technology (KIT) | Eggenstein-Leopoldshafen | Germany | operational | 2014 | DME<br>gasoline-type fuels | 608<br>360 | t/y<br>t/y |
| Enerkem | Varennes | Canada | under construction | 2025 | methanol | 99000 | t/y |
| BioTfueL-consortium | Dunkirk | France | operational | 2021 | FT liquids<br>SAF | 60 | t/y |
| Engie + consortium | Lyon | France | operational | 2017 | SNG | 0.1 | t/y |
| Woodland Biofuels | Sarnia, Ontario | Canada | operational | 2013 | ethanol | 601 | t/y |
| Fulcrum (Sierra Biofuels) | Storey County | United States | cancelled | 2022 | FT liquids<br>SAF | 30000 | t/y |
| Advanced Biofuels Solutions Ltd | Swindon | United Kingdom | operational | 2022 | SNG<br>hydrogen | 1500<br>500 | t/y<br>t/y |
| Rottneros | Vallvik | Sweden | cancelled | | methanol | 140000 | t/y |
| Red Rock Biofuels | Lakeview | United States | idle | 2022 | FT liquids<br>SAF | 44000 | t/y |
| ThermoChem Recovery International (TRI) | Durham | United States | operational | 2009 | FT liquids | 1 | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sunshine Kaidi | Kemi | Finland | cancelled | 2019 | FT liquids | 200000 | t/y |
| Surrey Municipality | Surrey | Canada | operational | 2018 | SNG | 240 | t/y |
| Joint Venture of Air Liquide, Enerkem, Port of Rotterdam and Shell | Rotterdam | Netherlands | on hold | 2026 | SAF<br>chemicals | 60000 | t/y |
| Enerkem, SA (Agbar), Repsol | El Morell | Spain | planned | 2026 | methanol | 265000 | t/y |
| Velocys | Immingham | United Kingdom | planned | 2027 | SAF<br>renewable naphta | 58000 | t/y |
| Velocys | Natchez | United States | planned | 2026 | FT liquids | 72000 | t/y |
| Eni | Porto Marghera | Italy | planned | | Hydrogen<br>methanol | 0.1 | t/y |
| Fulcrum BioEnergy and Essar Oil | Ellesmere Port | United Kingdom | planned | 2027 | FT liquids<br>SAF | 70000 | t/y |
| Fulcrum Bioenergy | Gary | United States | on hold | 2025 | FT liquids<br>SAF | 90000 | t/y |
| Technische Universtität Darmstadt | Darmstadt | Germany | operational | 2010 | FT liquids | n.a. | t/y |
| DTU Chemical engineering | Roskilde | Denmark | operational | 2002 | clean syngas | n.a. | t/y |
| KEW Technology Ltd. | Wednesbury | United Kingdom | operational | 2021 | diesel-type hydrocarbons<br>power | n.a.<br>2 | t/y<br>MW |
| GIDARA Energy B.V. | Amsterdam | Netherlands | planned | 2025 | methanol | 87500 | t/y |
| Biojet AS | Follum | Norway | planned | | SAF | n.a. | t/y |
| Strategic Biofuels LLC | Caldwell Parish | United States | planned | 2027 | FT liquids | 110000 | t/y |
| BEST - Bioenergy and Sustainable | Wien-Simmering | Austria | operational | 2022 | FT liquids<br>clean syngas | 44 | t/y |

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|---|---|---|---|---|---|---|---|
| Technologies GmbH | | | | | | | |
| GIDARA Energy | Rotterdam | Netherlands | planned | 2025 | methanol | 87500 | t/y |
| Perpetual next | Delfzijl | Netherlands | planned | 2028 | methanol | 220000 | t/y |
| Perpetual next | Baltania | Estonia | planned | 2028 | methanol | 220000 | t/y |
| DG Fuels | St. James Parish | United States | planned | 2028 | sustainable aviation fuels SAF | 600000 | t/y |
| Advanced Bioenergy Lab eGen | Zeltweg | Austria | planned | 2027 | SNG | 7 | MW |

*Table 12: List of Hydrothermal Liquefaction Facilities*

| Company | Location | Country | Status | Startup | Product | Capacity | Unit |
|---|---|---|---|---|---|---|---|
| Licella | Somersby | Australia | non operational | 2008 | bio-oil | 350 | t/y |
| Steeper Energy | Aalborg | Denmark | operational | 2013 | bio-oil | 24 | t/y |
| Aarhus University | Foulum | Denmark | operational | 2015 | bio-oil | 30 | t/y |
| Silva Green Fuel | Tofte | Norway | operational | 2021 | bio-oil | 1400 | t/y |
| Arbios Biotech (JV Canfor Licella) | Prince George | Canada | under construction | 2024 | bio-oil | 9550 | t/y |
| Licella | Somersby | Australia | operational | 2015 | bio-oil | 1 | t/y |
| Arbios Biotech (Joint Venture of Licella and Canfor) | Somersby | Australia | operational | 2021 | bio-oil | 1800 | t/y |
| Steeper Energy | Calgary | Canada | operational | 2021 | bio-oil | n.a. | t/y |
| Steeper Energy | Alberta | Canada | planned | | bio-oil | n.a. | t/y |

*Table 13: List of Hydrotreatmen Facilities*

| Company | Location | Country | Status | Startup | Product | Capacity | Unit |
|---|---|---|---|---|---|---|---|
| Neste | Porvoo | Finland | operational | 2009 | RD (HVO) | 90000 | t/y |

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|---|---|---|---|---|---|---|---|
| | | | | | SAF | 100000 | t/y |
| Neste | Rotterdam | Netherlands | operational | 2011 | RD (HVO)<br>SAF | 800000 | t/y |
| Neste | Singapore | Singapore | operational | 2010 | RD (HVO)<br>SAF | 800000 | t/y |
| Neste | Porvoo | Finland | operational | 2007 | RD (HVO)<br>SAF | 190000 | t/y |
| UPM Biofuels | Lappeenranta | Finland | operational | 2015 | RD (HVO)<br>renewable naphta | 130000 | t/y |
| REG Geismar | Geismar | United States | operational | 2010 | RD (HVO) | 225000 | t/y |
| Cepsa La Rabida research | La Rabida | Spain | operational | 2011 | RD (HVO) | 50000 | t/y |
| Cepsa | San Roque | Spain | operational | 2011 | RD (HVO) | 50000 | t/y |
| ENI | Porto Marghera | Italy | operational | 2014 | RD (HVO) | 360000 | t/y |
| Preem | Gothenburg | Sweden | operational | 2015 | RD (HVO)<br>gasoline-type fuels<br>bioLPG | 288000 | t/y |
| Diamond Green Diesel | Norco, LA | United States | operational | 2014 | RD (HVO) | 2000000 | t/y |
| Neste | Naantali | Finland | cancelled | 2014 | RD (HVO) | 40000 | t/y |
| Aemetis | Riverbank | United States | planned | 2026 | RD (HVO)<br>SAF | 74000 | t/y |
| Total | La Mede | France | operational | 2019 | RD (HVO)<br>SAF | 500000 | t/y |
| SunPine | Pitea | Sweden | operational | 2010 | RD (HVO) | 77000 | t/y |
| SunPine | Pitea | Sweden | operational | 2021 | RD (HVO) | 39000 | t/y |
| St1 and SCA in joint venture | Gothenburg | Sweden | operational | 2024 | RD (HVO)<br>SAF | 200000 | t/y |
| Neste | | Singapore | operational | 2023 | RD (HVO)<br>SAF | 1300000 | t/y |
| SkyNRG | Delfzijl | Netherlands | planned | 2025 | SAF<br>bioLPG<br>renewable | 100000<br>15000 | t/y<br>t/y |

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|---|---|---|---|---|---|---|---|
| | | | | | naphtha | 20000 | t/y |
| UPM Biofuels | Rotterdam | Netherlands | planned | | RD (HVO) | 500000 | t/y |
| ECB Group | Asuncion | Paraguay | planned | 2025 | RD (HVO)<br>SAF | 900000 | t/y |
| OMV | Schwechat | Austria | operational | 2024 | diesel with biogenic content<br>SAF | 160000 | t/y |
| Total | Grandpuits-Bailly-Carrois | France | planned | 2025 | SAF<br>RD (HVO)<br>renewable naphtha | 210000<br>50000<br>70000 | t/y<br>t/y<br>t/y |
| World Energy | Paramount | United States | operational | | RD (HVO)<br>SAF | 780000 | t/y |
| World Energy | Paramount | United States | operational | 2020 | RD (HVO)<br>SAF | 101000 | t/y |
| Emerald Biofuels | Port Arthur | United States | no status | | RD (HVO) | 325000 | t/y |
| Phillips 66 | San Francisco | United States | operational | 2024 | RD (HVO)<br>SAF<br>gasoline-type fuels | 1560000 | t/y |
| Eni | Gela | Italy | operational | 2019 | RD (HVO)<br>SAF | 750000 | t/y |
| REG Geismar | Geismar | United States | planned | 2024 | RD (HVO) | 1000000 | t/y |
| SCA | Östrand | Sweden | planned | 2029 | RD (HVO) | 300000 | t/y |
| CSIR-Indian Institute of Petroleum | Dehradun | India | no status | 2017 | SAF | n.a. | t/y |
| GreenflexJET Consortium | Berkeley | United Kingdom | no status | 2023 | SAF | 1200 | t/y |
| Repsol | Cartagena | Spain | operational | 2024 | RD (HVO)<br>SAF<br>renewable naphtha | 250000 | t/y |
| Greenergy | Teesside | United Kingdom | planned | 2027 | RD (HVO)<br>SAF | n.a. | t/y |

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|---|---|---|---|---|---|---|---|
| CVR Energy Inc. | Wynnewood | United States | operational | 2022 | RD (HVO)<br>renewable naphtha | 295000<br>16000 | t/y<br>t/y |
| Preem | Lysekil | Sweden | under construction | 2024 | RD (HVO)<br>gasoline-type fuels | 700000 | t/y |
| Neste | Rotterdam | Netherlands | planned | 2026 | SAF | 500000 | t/y |
| Tidewater | Prince George | Canada | operational | 2023 | RD (HVO) | 150000 | t/y |
| Fintoil | Hamina | Finland | operational | 2022 | RD (HVO) | 78000 | t/y |
| Consortium: JGC, Cosmo Oil, Revo Int'l | Sakai-shi | Japan | under construction | 2025 | SAF<br>RD (HVO)<br>renewable naphtha | 23400 | t/y |
| Imperial Oil | Edmonton | Canada | under construction | 2025 | RD (HVO) | 780000 | t/y |
| BP | Cherry Point | United States | operational | 2018 | RD (HVO) | 320000 | t/y |
| Shell | Rotterdam | Netherlands | on hold | 2024 | SAF<br>RD (HVO( | 410000<br>410000 | t/y<br>t/y |
| Marathon Petroleum | Dickinson | United States | operational | 2020 | RD (HVO)<br>renewable naphtha | 550000 | t/y |
| Marathon Petroleum and Neste (Joint venture) | Martinez | United States | operational | 2022 | RD (HVO)<br>renewable naphtha | 2100000 | t/y |
| Cargill and Love's Family of Companies (Joint venture Heartwell Renewables) | Hastings | United States | planned | 2024 | RD (HVO) | 235000 | t/y |
| Eni SPA | Taranto | Italy | operational | 2021 | RD (HVO)<br>SAF | n.a. | t/y |
| Eni | Livorno | Italy | operational | 2022 | SAF | 10000 | t/y |
| BP | Castellon | Spain | operational | 2021 | SAF | n.a. | t/y |
| Covenant Energy | | Canada | planned | 2026 | RD (HVO) | 350000 | t/y |

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|---|---|---|---|---|---|---|---|
| Cresta | Come by Chance | Canada | operational | 2024 | SAF | 800000 | t/y |
| Federated Co-operative | Regina | Canada | planned | 2027 | RD (HVO) | 780000 | t/y |
| Repsol | Puertollano | Spain | planned | 2025 | RD (HVO) | 240000 | t/y |
| ECO Ceres | Zhangjiagang | China | operational | 2018 | RD (HVO)<br>SAF | 320000 | t/y |
| Indaba Renewable Fuels | Imperial | United States | planned | 2024 | RD (HVO)<br>SAF | 295000 | t/y |
| Indaba Renewable Fuels | | United States | planned | 2024 | RD (HVO)<br>SAF | 295000 | t/y |
| Montana Renewables | Great Falls | United States | operational | 2022 | RD (HVO)<br>SAF | 600000 | t/y |
| Seaboard Energy | Hugoton | United States | operational | 2022 | RD (HVO) | 250000 | t/y |
| Eni | Livorno | Italy | planned | 2026 | RD (HVO) | 500000 | t/y |
| Cepsa and Bio-Oil | Huelva | Spain | planned | 2026 | SAF<br>RD (HVO) | 500000 | t/y |
| Preem | Lysekil | Sweden | operational | 2023 | diesel with biogenic content<br>RD (HVO) | 57000<br>78000 | t/y<br>t/y |
| Preem | Lysekil | Sweden | planned | 2030 | RD (HVO)<br>gasoline-type fuels | 900000 | t/y |
| Preem | Gothenburg | Sweden | planned | 2030 | RD (HVO)<br>SAF | 780000 | t/y |
| Brasil Biofuels | Manaus | Brazil | planned | 2025 | RD (HVO)<br>SAF | 20000<br>20000 | t/y<br>t/y |
| Acelen | São Francisco do Conde | Brazil | planned | 2025 | RD (HVO)<br>SAF | 40000<br>40000 | t/y<br>t/y |
| HOLBORN Europa Raffinerie | Hamburg | Germany | planned | 2027 | RD (HVO)<br>SAF | 220000 | t/y |
| Guangxi Hongkun | Guangxi | China | planned | 2026 | RD (HVO) | n.a. | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Biomass | | | | | SAF | | |
| Bangchak and Sumitomo | Bangkok | Thailand | under construction | 2025 | SAF | 280000 | t/y |
| Revo Int'l | Tahara-shi | Japan | operational | 2024 | SAF<br>RD (HVO)<br>renewable naphtha | 23400 | t/y |
| Eneos | Arita-shi | Japan | under construction | 2026 | SAF<br>RD (HVO)<br>renewable naphtha | 312000 | t/y |
| Idemitsu | Shunan-shi | Japan | planned | 2029 | SAF<br>RD (HVO)<br>renewable naphtha | 195000 | t/y |
| Consortium: Environment Energy, Univ of Kitakyushu, HIBD Research Institute | Kitakyushu-shi | Japan | operational | | SAF<br>RD (HVO)<br>renewable naphtha | n.a. | t/y |
| Greenergy | Teesside | United Kingdom | planned | 2027 | SAF | n.a. | t/y |
| Refuel Energy Inc | Toronto | Canada | planned | 2025 | RD (HVO)<br>SAF | 128000<br>20000 | t/y<br>t/y |
| SINOPEC | Zhenhai | China | operational | 2020 | SAF | 100000 | t/y |
| Henan Junheng Industry Group Biotechnology Co. LTD | Henan | China | operational | | SAF | 10000 | t/y |
| Riograndense | Rio Grande | Brazil | planned | 2028 | RD (HVO)<br>SAF | 800000 | t/y |
| Diamond Green Diesel | Port Arthur | United States | operational | 2022 | RD (HVO)<br>SAF | 690000<br>690000 | t/y<br>t/y |

*Table 14: List of Other Technologies Facilities*

| Company | Location | Country | Status | Startup | Product | Capacity | Unit |
|---|---|---|---|---|---|---|---|
| BioMCN (OCI NV) | Farmsum | Netherlands | operational | 2009 | methanol | 65000 | t/y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RenFuel | Vallvik | Sweden | cancelled | | bio-oil | 240000 | t/y |
| Sodra | Monsteras | Sweden | operational | 2020 | methanol | 5250 | t/y |
| Ekobenz - acquired by Vertimass | Kleszczow | Poland | operational | 2019 | gasoline-type fuels | 22500 | t/y |

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