



IEA Bioenergy

Technology Collaboration Programme

Development and Deployment of advanced biofuel demonstration facilities

IEA Bioenergy: Task 39

December 2024





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Andrea Sonnleitner, Dina Bacovsky

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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.

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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 decrease 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).

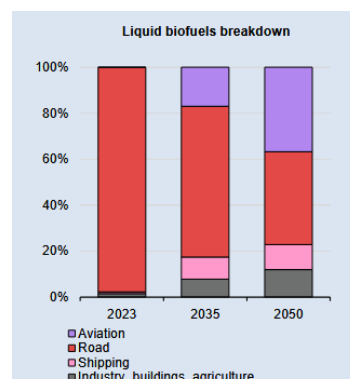


Figure 1 share of liquid biofuels per sector

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 an 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 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.

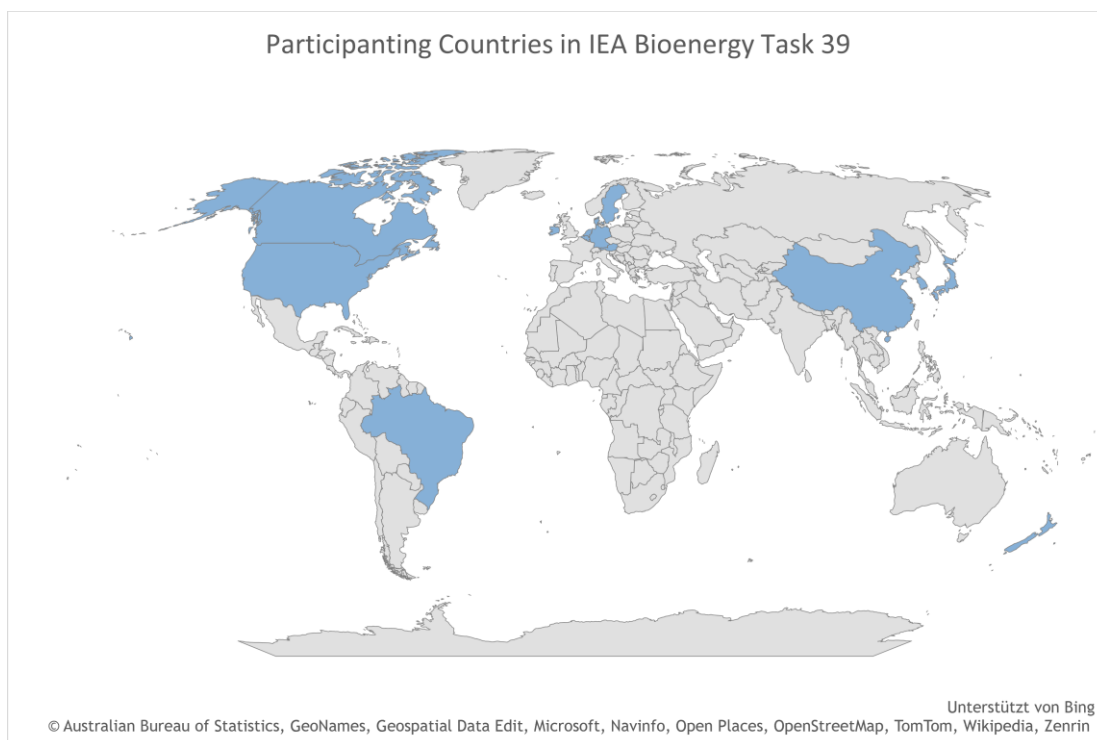


Figure 2: Participating countries in IEA Bioenergy Task 39 2022-2024

The projects or topics worked on in IEA Bioenergy Task 39 include technological topics (SAF/biojet, drop-in fuels, marine fuels, synergies with green hydrogen), market-related topics (demonstration facilities, commercialisation 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).

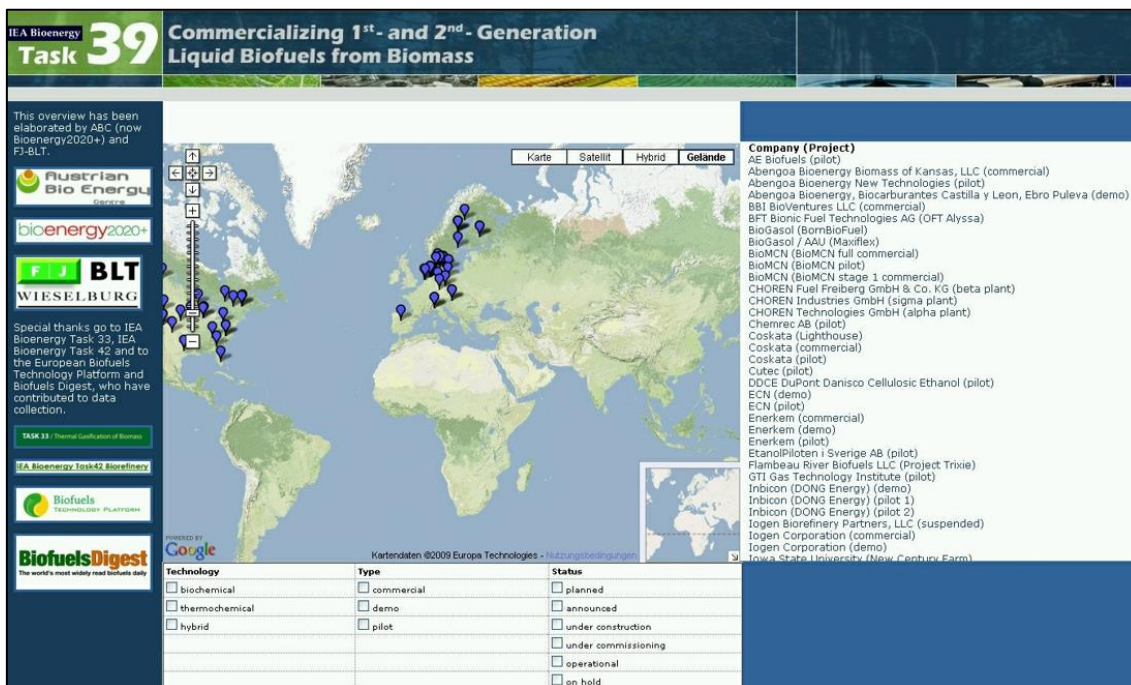


Figure 3: Screenshot of the first appearance of the Task 39 database

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.

Task 39: Biofuels to decarbonize transport

Database on facilities for the production of advanced liquid and gaseous biofuels for transport

Search Owner/Name/Input [Submit]

Owner	Name	Location	Info
Aarhus University	Center for Biorefining Technologies	Denmark	Info
Acelen	Acelen Bahia	Brazil	Info
Advanced Biofuels Solutions Ltd	Swindon Advanced Biofuels Plant	United Kingdom	Info
Aemetis	Aemetis Carbon Zero 1	United States	Info
ALTACA ENERGY	ALTACA ENERGY	Turkey	Info
Amyris, Inc.	Amyris Tate & Lyle	United States	Info
Anhui BBKA Biochemical	BBKA	China	Info
Anhui Guozhen Group and Chemtex Chemical Engineering	Fuyang project	China	Info
AquaGreen ApS	AquaGreen PCE	Denmark	Info
AquaGreen ApS	AquaGreen/Farevejle wastewater facility	Denmark	Info
Arbrios Biotech (Joint Venture of Licella and Canfor)	CS-1 Facility	Australia	Info
Arbrios Biotech (JV Canfor Licella)	Chuntoh Ghuna Low-carbon Biofuel Plant	Canada	Info
Arbor Renewable Gas LLC	Spindletop Plant	United States	Info
ArcelorMittal	Ghent Steelanol	Belgium	Info
Assam Bio Refinery (ABRPL)	2G ethanol Commercial plant	India	Info
AustroCel Hallein	biorefinery	Austria	Info

Map: operational | under construction | planned | non operational | no status

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.

Filter Projects

Type	Technology	Status	Raw Material	Output
<input type="checkbox"/> TRL 1-3 Research	<input type="checkbox"/> Alcohol-to-jet	<input type="checkbox"/> no status	<input type="checkbox"/> agricultural residues	<input type="checkbox"/> bio-oil
<input type="checkbox"/> TRL 4-5 Pilot	<input type="checkbox"/> E-Fuels Biomass Hybrids	<input type="checkbox"/> planned	<input type="checkbox"/> biomass / biomass coal blends	<input type="checkbox"/> biogas
<input type="checkbox"/> TRL 6-7 Demonstration	<input type="checkbox"/> Fast Pyrolysis	<input type="checkbox"/> under construction	<input type="checkbox"/> forest residues	<input type="checkbox"/> butanol
<input type="checkbox"/> TRL 8 First-of-a-kind commercial	<input type="checkbox"/> Fermentation	<input type="checkbox"/> operational	<input type="checkbox"/> lignocellulosics	<input type="checkbox"/> clean syngas
<input type="checkbox"/> TRL 9 Commercial	<input type="checkbox"/> Gasification	<input type="checkbox"/> non operational	<input type="checkbox"/> oilcrops, oils and fats	<input type="checkbox"/> diesel-type hydrocarbons
	<input type="checkbox"/> Hydrothermal Liquefaction	<input type="checkbox"/> cancelled	<input type="checkbox"/> organic residues and waste streams	<input type="checkbox"/> diesel with biogenic content
	<input type="checkbox"/> Hydrotreatment	<input type="checkbox"/> idle	<input type="checkbox"/> other	<input type="checkbox"/> DME
	<input type="checkbox"/> Lignin Depolymerisation	<input type="checkbox"/> on hold	<input type="checkbox"/> sugar and starch crops	<input type="checkbox"/> ethanol
	<input type="checkbox"/> Other Technology		<input type="checkbox"/> unknown	<input type="checkbox"/> FT liquids
			<input type="checkbox"/> waste gases	<input type="checkbox"/> gasoline-type fuels
				<input type="checkbox"/> heat
				<input type="checkbox"/> hydrogen
				<input type="checkbox"/> isobutene
				<input type="checkbox"/> methanol
				<input type="checkbox"/> other
				<input type="checkbox"/> pyrolysis oil
				<input type="checkbox"/> renewable diesel (HVO)
				<input type="checkbox"/> SNG
				<input type="checkbox"/> sustainable aviation fuels SAF

[Submit]

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 Location of the production facility Type of technology Raw material Product Output capacity Type of facility Status and Contact information
Optional data	Start up year Additional information on technology and input capacity Information on investment and funding Partners Brief technology description 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	<ol style="list-style-type: none"> 1. basic principles observed 2. technology concept formulated 3. experimental proof of concept
TRL 4-5 Pilot	<ol style="list-style-type: none"> 4. technology validated in lab 5. technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6-7 Demonstration	<ol style="list-style-type: none"> 6. technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies) 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:

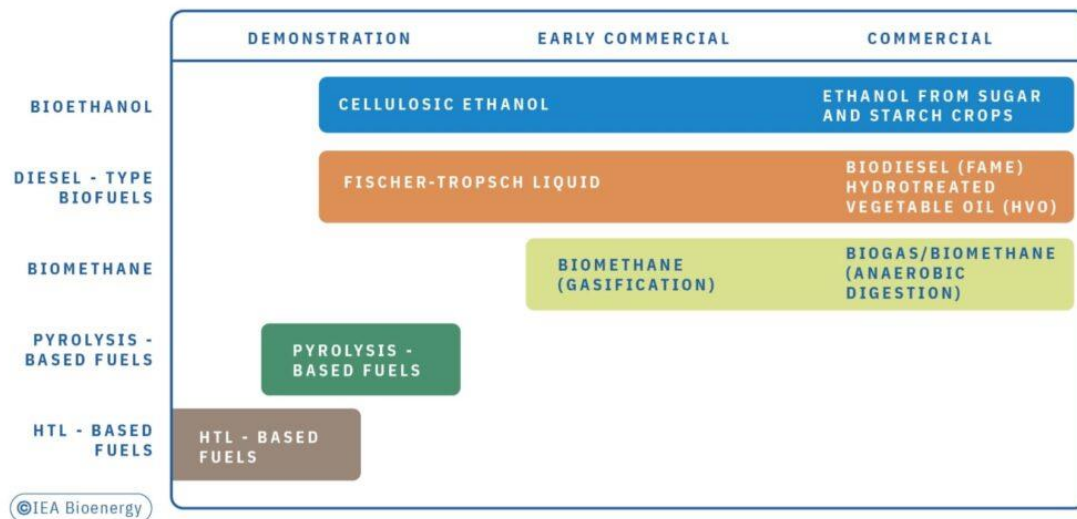


Figure 6: Overview of technology pathways and their technology readiness level (IEA Bioenergy, 2023)

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.

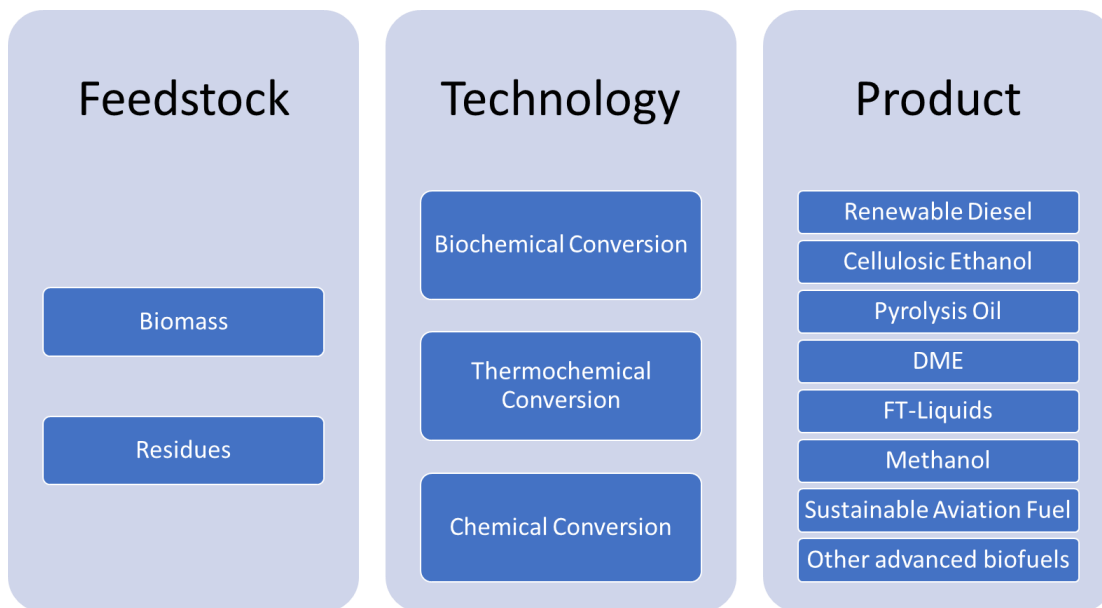


Figure 7: Principle pathways of advanced biofuels technologies

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.

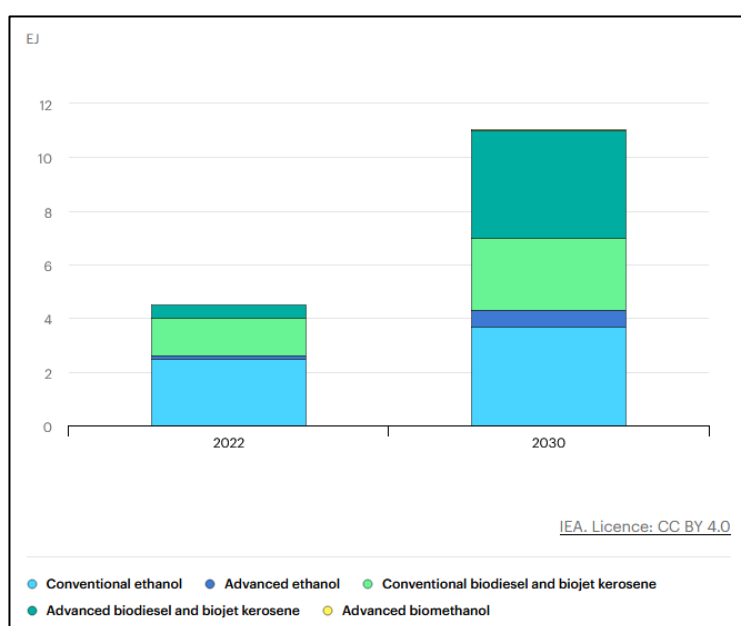


Figure 8: Liquid biofuel production by feedstock and technology in Net Zero Scenario, 2022 and 2030 (IEA, 2023 b)

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:

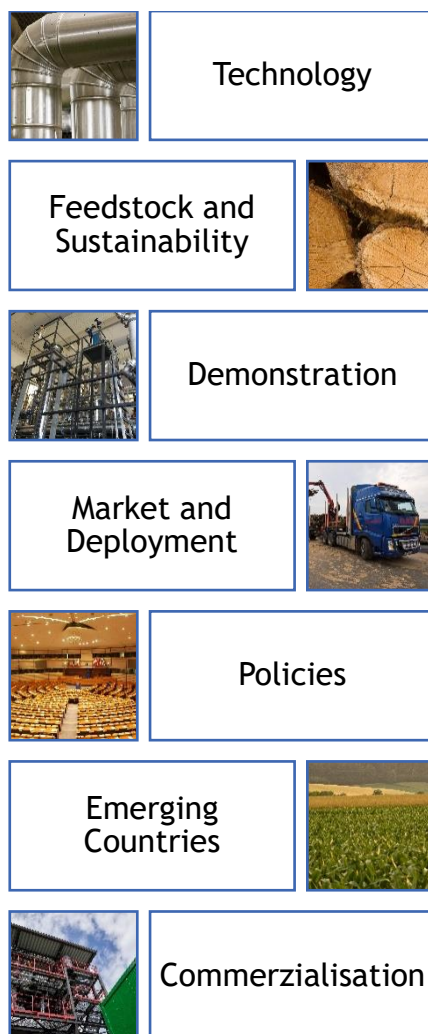


Figure 9: Thematic areas with recent development

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 CO₂ from a biofuel production process can be used as carbon source for e-fuel production or H₂ 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 CO₂ 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 CO₂.

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.

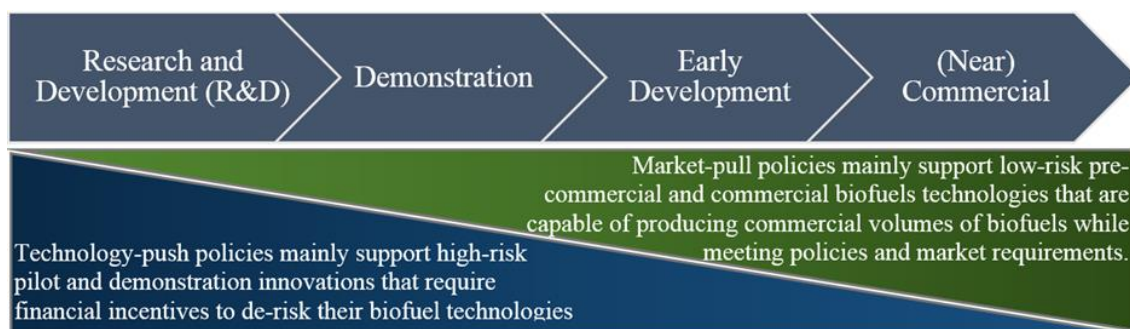


Figure 10: Technology-push and market-pull biofuel policies from IEA AMF and IEA Bioenergy (IEA AMF and IEA Bioenergy, 2020)

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) ReFuel Aviation FuelEU Maritime EU-ETS (Emission Trading System)
USA and Canada	Inflation Reduction Act (IRA) US Renewable Fuels Standard (RFS) California Low Carbon Fuel Standard (LCFS) Canadian Clean Fuel Standard (CFS)
Brazil	RenovaBio Fuels of the Future Program
India	Roadmap for Ethanol Blending in India National Policy on Biofuels
China	Action plan for carbon dioxide peaking before 2030 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).

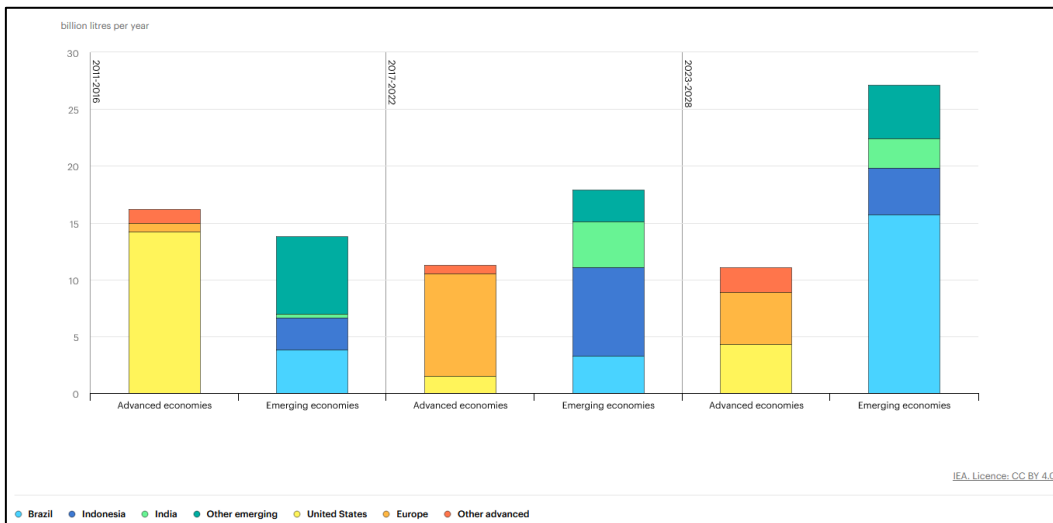


Figure 11: Biofuel demand growth for advanced and emerging economies (IEA, 2024 b)

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 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 in the 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.

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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 RD (HVO)	27000 3000	t/y t/y
Gevo	Lake Preston	United States	planned	2026	SAF Renewable naphtha	180000	t/y
Consortium: Biomaterial in Tokyo(bits), Sanyu Plant Service	Shikokuchuo- shi	Japan	planned	2025	Ethanol SAF Renewable naphtha	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 RD (HVO) 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 renewable naphta	75000 35000	t/y 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
Nexoil 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 clean syngas	6000	m3/y
BTG-BTL	Hengelo	Netherlands	operational	2015	pyrolysis oil steam 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 steam power	24000 8 0.7er	t/y MW 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	Amlı	Norway	on hold		pyrolysis oil	100000	t/y
Green Fuel Nordic	Liekka	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 solid fuels	n.a.	t/y
DTU Chemical engineering	Roskilde	Denmark	non operational	2002	clean syngas bio-oil solid fuels	n.a.	t/y
AquaGreen ApS	Roskilde	Denmark	operational		clean syngas solid fuels	n.a.	t/y
AquaGreen ApS	Farevejle	Denmark	operational	2022	clean syngas 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 solid fuels clean syngas	450 2000 780	t/y t/y t/y
Stiesdal SkyClean A/S	Vrå	Denmark	under construction	2024	Heat solid fuels	20 14000	MW t/y
Frichs Pyrolysis ApS	Horsens	Denmark	under construction	2024	clean syngas 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	110 110	t/y 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 BBKA 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 biogas lignin	65000 30 230000	t/y MW 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	Sertãozinho	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	m ³ /h
Enerkem	Montreal	Canada	operational	2003	Ethanol methanol SNG	375 475	t/y m ³ /y
GTI Gas Technology Institute	Des Plaines	United States	operational		Heat gasoline-type fuels	5 38	MWth m ³ /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 heat	200 50	MW MWth
Enerkem Alberta Biofuels LP	Edmonton	Canada	non operational	2014	Ethanol methanol chemicals	30000	t/y
Enerkem	Westbury	Canada	operational	2009	Ethanol methanol chemicals	4000	t/y
Thermochem Recovery International	Durham	United States	operational	2007	FT liquids mixed alcohols power	n.a.	t/y
Karlsruhe Institute of Technology (KIT)	Eggenstein-Leopoldshafen	Germany	operational	2014	DME gasoline-type fuels	608 360	t/y t/y
Enerkem	Varenes	Canada	under construction	2025	methanol	99000	t/y
BioTfuel-consortium	Dunkirk	France	operational	2021	FT liquids 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 SAF	30000	t/y
Advanced Biofuels Solutions Ltd	Swindon	United Kingdom	operational	2022	SNG hydrogen	1500 500	t/y t/y
Rottneros	Vallvik	Sweden	cancelled		methanol	140000	t/y
Red Rock Biofuels	Lakeview	United States	idle	2022	FT liquids 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, Enkern, Port of Rotterdam and Shell	Rotterdam	Netherlands	on hold	2026	SAF chemicals	60000	t/y
Enkern, SA (Agbar), Repsol	El Morell	Spain	planned	2026	methanol	265000	t/y
Velocys	Immingham	United Kingdom	planned	2027	SAF renewable naphtha	58000	t/y
Velocys	Natchez	United States	planned	2026	FT liquids	72000	t/y
Eni	Porto Marghera	Italy	planned		Hydrogen methanol	0.1	t/y
Fulcrum BioEnergy and Essar Oil	Ellesmere Port	United Kingdom	planned	2027	FT liquids SAF	70000	t/y
Fulcrum Bioenergy	Gary	United States	on hold	2025	FT liquids SAF	90000	t/y
Technische Universität 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 power	n.a. 2	t/y 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 clean syngas	44	t/y

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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 Hydrotreatment Facilities

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

					SAF	100000	t/y
Neste	Rotterdam	Netherlands	operational	2011	RD (HVO) SAF	800000	t/y
Neste	Singapore	Singapore	operational	2010	RD (HVO) SAF	800000	t/y
Neste	Porvoo	Finland	operational	2007	RD (HVO) SAF	190000	t/y
UPM Biofuels	Lappeenranta	Finland	operational	2015	RD (HVO) 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) gasoline- type fuels 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) SAF	74000	t/y
Total	La Mede	France	operational	2019	RD (HVO) 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) SAF	200000	t/y
Neste		Singapore	operational	2023	RD (HVO) SAF	1300000	t/y
SkyNRG	Delfzijl	Netherlands	planned	2025	SAF bioLPG renewable	100000 15000	t/y t/y

					naphtha	20000	t/y
UPM Biofuels	Rotterdam	Netherlands	planned		RD (HVO)	500000	t/y
ECB Group	Asuncion	Paraguay	planned	2025	RD (HVO) SAF	900000	t/y
OMV	Schwechat	Austria	operational	2024	diesel with biogenic content SAF	160000	t/y
Total	Grandpuits- Bailly-Carrois	France	planned	2025	SAF RD (HVO) renewable naphtha	210000 50000 70000	t/y t/y t/y
World Energy	Paramount	United States	operational		RD (HVO) SAF	780000	t/y
World Energy	Paramount	United States	operational	2020	RD (HVO) 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) SAF gasoline- type fuels	1560000	t/y
Eni	Gela	Italy	operational	2019	RD (HVO) 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) SAF renewable naphtha	250000	t/y
Greenergy	Teesside	United Kingdom	planned	2027	RD (HVO) SAF	n.a.	t/y

CVR Energy Inc.	Wynnewood	United States	operational	2022	RD (HVO) renewable naphtha	295000 16000	t/y t/y
Preem	Lysekil	Sweden	under construction	2024	RD (HVO) 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 RD (HVO) 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 RD (HVO)	410000 410000	t/y t/y
Marathon Petroleum	Dickinson	United States	operational	2020	RD (HVO) renewable naphtha	550000	t/y
Marathon Petroleum and Neste (Joint venture)	Martinez	United States	operational	2022	RD (HVO) 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) 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

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) SAF	320000	t/y
Indaba Renewable Fuels	Imperial	United States	planned	2024	RD (HVO) SAF	295000	t/y
Indaba Renewable Fuels		United States	planned	2024	RD (HVO) SAF	295000	t/y
Montana Renewables	Great Falls	United States	operational	2022	RD (HVO) 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 RD (HVO)	500000	t/y
Preem	Lysekil	Sweden	operational	2023	diesel with biogenic content RD (HVO)	57000 78000	t/y t/y
Preem	Lysekil	Sweden	planned	2030	RD (HVO) gasoline-type fuels	900000	t/y
Preem	Gothenburg	Sweden	planned	2030	RD (HVO) SAF	780000	t/y
Brasil Biofuels	Manaus	Brazil	planned	2025	RD (HVO) SAF	20000 20000	t/y t/y
Acelen	São Francisco do Conde	Brazil	planned	2025	RD (HVO) SAF	40000 40000	t/y t/y
HOLBORN Europa Raffinerie	Hamburg	Germany	planned	2027	RD (HVO) 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 RD (HVO) renewable naphtha	23400	t/y
Eneos	Arita-shi	Japan	under construction	2026	SAF RD (HVO) renewable naphtha	312000	t/y
Idemitsu	Shunan-shi	Japan	planned	2029	SAF RD (HVO) renewable naphtha	195000	t/y
Consortium: Environment Energy, Univ of Kitakyushu, HIBD Research Institute	Kitakyushu-shi	Japan	operational		SAF RD (HVO) 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) SAF	128000 20000	t/y 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) SAF	800000	t/y
Diamond Green Diesel	Port Arthur	United States	operational	2022	RD (HVO) SAF	690000 690000	t/y 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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