GLAMOUR

Glycerol to Biofuel: market, technologies and players

Based on the EU project GLAMOUR,
D7.4 Market Analysis and Stakeholders report

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PNO CiaoTech

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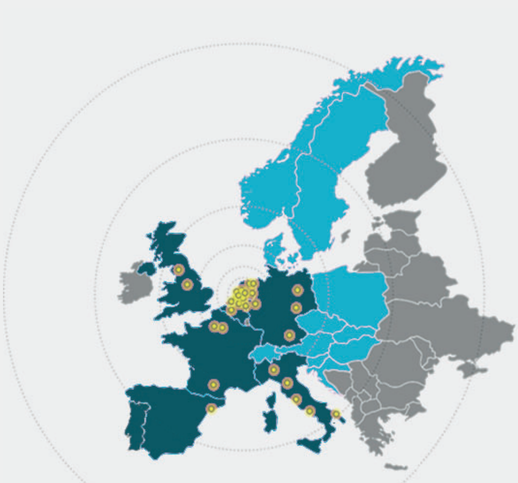

KEY FACTS

35+
Years of activity

8
Countries

2000+
Open Innovation project per year

4.000+
Funded projects and partners in our intelligence tool

70.000+
Qualified RD&I partners

€ 1Bn
Total annual funding won

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Wheesbee harvests, homogenises, indexes and analyses millions of documents, patents, scientific papers, funding programmes, web pages, funded R&D project, and company information.

+6000
FUNDING OPPORTUNITIES

+300
ANNUAL COLLABORATION OPPORTUNITIES

+1Mln
FUNDED PROJECTS

+400Mln
PATENTS AND PAPERS

+160k
INNOVATIVE ORGANIZATIONS

CONTENTS

LIST OF ABBREVIATIONS AND DEFINITIONS

CAGR	Compounded Average Growth Rate
CPC	Cooperative Patent Classification
EEA	European Environmental Agency
FAME	Fatty Acid Methyl Ester
HEFA	Hydro-processed esters and fatty acids
HVO	Hydrogenated Vegetable Oil
IEA	International Energy Agency
ILUC	Indirect Land-Use Change
IP	Intellectual Property
FT	Fischer-Tropsch
FT- SPK	Fischer-Tropsch Synthetic Paraffinic Kerosene
IP	Intellectual Property
MDO	Marine diesel oil
RTO	Research and Technology Organisation
R&D	Research and Development
SAF	Sustainable Aviation Fuel
SDG	Sustainable Development Goal
SDS	Sustainable Development Scenario
TRL	Technology Readiness Level

INTRODUCTION

ABOUT THIS REPORT

Biofuels are among the most promising options to decarbonise transport in the short to medium term especially for aviation and maritime sectors that lack immediate alternatives. Their production and market uptake, however, is still very low due to several challenges affecting their value chain.

This report provides a combination of market outlook and technology intelligence, addressing the topic of advanced biofuels for aviation and maritime sector and considering the case study of the European project GLAMOUR. Starting from briefly introducing the policy context and market drivers for the development of innovative technologies for sustainable fuels, it presents a bird's view of market trends and potential. It also presents a selection of key market leaders that are at the core of technology development and R&D in the domain.

In this analysis, we acknowledge that a great amount of R&D has been focussing on the development of biofuels for aviation and maritime sectors. However, technology is still facing relevant barriers hindering the development of the biofuels production at industrial scale.

SUMMARY AND HIGHLIGHTS

Transport sector – opportunities and barriers for decarbonisation:

The transport sector is a major driver of climate change both globally and at European level. The aviation and maritime sectors are among the main contributors to overall greenhouse gas emissions, representing together about 28% of carbon emissions from the transport sector and about 5% of total emissions from human activities. Decarbonising these sectors has become a main priority for the EU, that has introduced an interconnected set of measures and policies aiming at counteracting the emissions from transport.

Biofuels are among the most promising options to decarbonise transport. However, in order to establish a solid market for advanced biofuels, the development of innovative technologies that allow to overcome major technical and economic bottlenecks should be incremented. Advances in this field will be crucial to convince investors to unlock sufficient financial resources.
Based on the conversion of crude glycerol, a highly available by-product from biodiesel plants, the European project GLAMOUR offers an example of a highly promising and scalable technology for the production of advanced biofuels for maritime and aviation.

Glycerol conversion into biofuels, supply capacity and demand:

Glycerol is considered a promising feedstock for advanced biofuels. The major source of glycerol today is the biodiesel industry. Dominating the global biodiesel market with about the 50% of the market share, the European biodiesel sector produces annually about 1.01 Mton of crude glycerol.

The advanced biofuels market which – compared to traditional biofuels - represents a more sustainable option for energy carriers production, is expected to have an impressive annual growth potential of over 38% CAGR until 2025. On the other hand, to be on track with the IEA's Sustainable Development Scenario for reaching key SDGs, the output of biofuels needs to grow of 10% compared to the estimated total biofuels production growth. Therefore, it is expected that the future demand for sustainable biofuels will not be satisfied by the actual production capacity in Europe.

Advanced biofuels development – Innovation trends and landscape:

In the last six years, the R&D on advanced biofuels from industrial waste or other sustainable feedstock has attracted more than € 78 million of public funding and mobilised private investments, which are expected supporting industrial and research players overcoming main technical barriers. Germany emerged as the most active European country for R&D in the advanced biofuel sector. The global patent landscape is dominated by the USA.

The largest majority of funded R&D in the domain are targeted at low-medium TRL levels, focussing on validation at lab-scale or relevant environment, while the demonstration and qualification at industrial level is still limited. Gasification and FT are the most investigated technologies, especially for aviation and other transport fuels.

R&D on advanced biofuels has seen a marked engagement of major European industries, such as the INERATEC, SkyNRG, GoodFuels and others, which have established collaborations with leading research centres and universities, of which some examples are the Spanish National Research Council (CSIC) and Eindhoven University of Technology (TU/e), Fraunhofer-Gesellschaft, the Norwegian University of Science and Technology (NTNU) and VTT Technical Research Center of Finland.

The establishment of a solid market for advanced biofuels will require in the next years large investments and innovation capabilities. According to this study, key companies that are expected to play a key role in this phase are Shell, Neste Oil and Johnson Matthey. Other specialised companies at European level that will be crucial to overcome residual bottlenecks enabling advanced biofuels to reach competitiveness are expected to be, for example, INERATEC and Vertoro, among others.

THE DECARBONISATION OF THE TRANSPORT SECTOR: A MAIN PRIORITY FOR THE EU

POLICY CONTEXT

The transport sector is a major driver of climate change both globally and at European level. **Transport is responsible for a quarter of total European carbon emissions, with this number expected to rise.** Initiatives promoting carbon-neutral mobility to help stop this negative trend are urgently needed.

While the EU as a whole is showing declining carbon emissions, transport-related emissions are higher than in 1990. The aviation and maritime sectors are among the main contributors to overall emissions related to transportation, both at European and global level:

- **Aviation emits about 3.8% of the EU's total GHG emissions and more than 2.5% of global emissions**[1]. In the absence of actions, emissions from EU-28 aviation will grow from 151 Mt[2] of CO_2 in 2015 to 405 Mt in 2050 (CO_2 emissions from aviation in 2019 in Europe were 151.8 Mt, representing 14% of total transport emissions).
- **Maritime consumes 330 Mt of fuel a year and accounts for 2-3% of global CO_2 emissions.** Shipping also accounts for up to 24% of all sulphur oxide (SOx), 24% of all nitrogen oxide (NOx) emissions and 9% of PM. The sector's overall share of emissions is expected to increase significantly, if seaborne trade grows at the current rate without any modifications and maintaining the technical status quo[3]. In the EU, **shipping emissions represent around 14% of the overall EU greenhouse gas emissions from the transport sector**[4].

According to the European Environmental Agency (EEA), although a reduction in transport emissions, particularly from aviation, was recorded in 2020 due the Covid-19 pandemic, traffic intensity is projected to rise again from 2021 and flight numbers are expected to return to 2019 levels by 2024 at the earliest, increasing again the emissions from this sector.

The EC has been acting on introducing an interconnected set of measures and policies aiming at counteracting the emissions of the transport sectors.

The **European Green Deal** – the strategy to turn Europe into the first "climate-neutral" continent - seeks a **90% reduction in transport emissions by 2050**. Such a target implies introducing, converting to and fostering the use of more sustainable transport means.

In July 2021, the EC launched the **Fit for 55 package**, a proposal to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net GHG emissions by at least 55% by 2030 (compared to 1990 level), creating a solid foundation for reaching this goal by giving a role to renewable liquid fuels in decarbonising transport.

Furthermore, the acceleration of the transition to a greener energy system is also crucial for the decarbonisation of the transport sector. The recently revised **Renewable Energy Directive** will set an increased target to produce **40% of our energy from renewable sources by 2030 and the new renewables target of GHG intensity reduction of at least 13 % by 2030 in the transport sector.**

Finally, as part of the *Fit for 55 package*, regulations contributing to the decarbonisation of transport sectors have been proposed:

- the **ReFuelEU Aviation Initiative** will oblige fuel suppliers to blend increasing levels of sustainable aviation fuels in jet fuel taken on-board at EU airports;
- similarly, the **FuelEU Maritime Initiative** will stimulate the uptake of sustainable maritime fuels and zero-emission technologies by setting a maximum limit on the GHG content of energy used by ships calling at European ports.

"With our three transport-specific initiatives – ReFuel Aviation, FuelEU Maritime and the Alternative Fuels Infrastructure Regulation – we will support the transport sector's transition into a future-proof system. We will create a market for sustainable alternative fuels and low-carbon technologies, while putting in place the right infrastructure to ensure the broad uptake of zero-emission vehicles and vessels. This package will take us beyond greening mobility and logistics. It is a chance to make the EU a lead-market for cutting-edge technologies."

Commissioner for Transport, Adina Vălean – July 2021

Biofuels: opportunities and limitations for the decarbonisation of the transport sector

Fuels derived from biomass, known as biofuels, are among the most 'technologically ready' solutions on the low-carbon pathway for the transport sector and they are therefore expected playing a key role for a sustainable transition of our transport system. However, biofuels have also proven to be highly controversial, due to questions related to their potential adverse sustainability, limited availability to meet the demand of the transport sector and high development costs.

Biofuels are fuels produced using organic feedstock (e.g., purpose-grown energy crops, residues from agriculture sector, municipal waste, among others). These feedstocks can be used to produce a variety of fuels with different properties and impacts.

Typically, a distinction is made between first-generation biofuels (or 'conventional' biofuels), produced from a feedstock that can also be used for food and feed and second-generation biofuels ('advanced' biofuels), produced from non-food crop feedstocks and thus not directly competing with food and feed crops for agricultural land or causing adverse sustainability impacts. First generation biofuels comprise the vast majority of biofuels currently in use, while second generation biofuels represent a very small percentage of biofuels currently produced, reaching only around 1-2% of total biofuel production by 2022. The higher production and commercialisation of first-generation biofuels represents a major problem to overcome, since **conventional biofuels are associated with the main sustainability issues,** including:

- **Land availability and use** – The amount of biomass required to replace a significant proportion of the fossil fuel used in transport runs into millions of tonnes, requiring enormous cropland areas to fulfil these needs and inducing a change in the land use. The indirect land-use change (iLUC) relates to the unintended consequences of releasing more carbon emissions due to land-use changes induced by the expansion of croplands for the production of biofuels. In addition, switching from growing food crops to bioenergy crops might impact food availability and price.

- **Environment** – Through direct and indirect land-use change from production of biofuel feedstocks, the risk of increasing GHG emissions occurs. In addition, other environmental issues related to conventional biofuels are the risks of degradation of land, forests, water resources and ecosystems.

- **Feedstock availability** - If no land-use change is involved, first-generation biofuels can have lower GHG emissions than fossil fuels, but the resulted feedstocks available are insufficient to meet the required amount for biofuels production.

These problems could be **partially sorted out with the adoption and production of second-generation biofuels.**

The current production of novel advanced biofuels is still modest, with progress needed to improve the technology readiness of viable production processes.

The development of innovative, scalable and costs competitive technologies for the development of advanced biofuels is urgently needed for de-risking large-scale investments in the field, solidify the biofuel market and to finally contribute setting a zero-emission pathway in the coming years.

These advanced technologies are important as they can utilise feedstocks with high availability and not limited to other uses (e.g., agricultural residues and municipal solid waste). However, in spite of the increased applicability potential compared to conventional biofuels, second-generation biofuels still do not overcome the **major limitations associated with feedstock availability**, which also include issues related to logistics and storage, along with the quality and variety of the biomass composition.

Another major boundary towards the adoption of advanced biofuels on large scale is represented by their poor cost competitiveness with respect to the fossil-based alternatives. Finally, the current structure of the biofuels business – especially of advanced biofuels - is highly fragmented, entailing high risks for potential investors. These include the uncertainty on long-term sourcing of reliable supplies of feedstocks (as mentioned above), the **high costs for deployment of innovative conversion technologies** not yet demonstrated at commercial level, and the **dependence on a stable and supportive long-term regulatory framework**. Together, these factors are responsible for reduced investments, hampering the development of a solid EU biofuels market.

The GLAMOUR project: a chance to decarbonise the EU transport sector

GLAMOUR

GLAMOUR - GLycerol to Aviation and Marine prOducts with sUstainable Recycling

The **GLAMOUR project** - GLycerol to Aviation and Marine prOducts with sUstainable Recycling – is a Horizon 2020 Research and Innovation project (Grant Agreement n° 884197).

The GLAMOUR project designs, scales-up and validates an integrated process that converts a bio-based feedstock (crude glycerol as waste of biodiesel plants) into aviation and maritime diesel fuels.

The technology combines a high-pressure, auto-thermal reforming/gasification using chemical looping to produce syngas and a Fischer-Tropsch compact reactor integrated with 3D printed structured catalyst. The GLAMOUR process aims for full conversion of crude glycerol into synthetic paraffine kerosene (FT-SPK) to be used as jet-fuel and into marine diesel oil with an energy efficiency of 65%. This would increase the overall revenue of existing second-generation biodiesel plants reducing the cost for large scale biomass-to-liquid production processes up to 35% and the CO_2 emissions up to 70%. The project focuses on the scale up to achieve a final TRL5 demonstration for 1,000 hours by using 2 kg/h of glycerol in a packed bed chemical looping systems and a downstream FT reactor.

The consortium: The GLAMOUR consortium includes **two universities** (University of Manchester and Eindhoven University of Technology), three large **research centres** (Netherland's Organisation of Applied Scientific Research – TNO, Spanish National Research Council – CSIC and the Flemish Institute for Technological Research – VITO) and 5 **industries** (Siirtec Nigi, Argent Energy, Ineratec, C&CS and Ciaotech).

Impact: The main goal is boost scale-up of biofuels to **decarbonize the expanding aviation and shipping sectors**, with the potential to:

- decrease cost of biofuel production with more than 35% compared to other benchmark technologies.
- decrease emissions equivalent to the 15% of aviation-based GHGs in EU, over a 10-year perspective.
- Generate a scalable business up to €11 bln/year in EU.

MARKET REVIEW AND OUTLOOK

Supply analysis: feedstock availability and market size

Glycerol is considered a promising feedstock for advanced biofuels, however other possibilities can be considered, based on two main variables: price and availability.

Viable alternatives to glycerol as previously identified[5], are *Brown Grease* (a mixture of oils, fats, solids and detergents from food wastes that are captured in grease traps), *Tank bottoms* (which are mainly residual waste fats from reactor bottoms in oleochemical processing) and *FOGs* (fats, oils and grease from the waste-water industry). These feedstocks have no exchange price, but their cost is low and availability potentially high. Glycerol remains a sound candidate for primary supply though: Figure 1 illustrates a summary of the market key-facts, while an additional review is built in the next paragraph.

Type		Applications	Geography	Supply Vs Demand
Crude Glycerol (CG)	Refined Glycerol (RG)	Technical Applications (e.g. automotive, building)	North America	Production
	Technical Grade		EU	Export
	United States Pharmacopeia (USP)	Pharmaceutical, Healthcare and hygene	International (China, Brasil, Indonesia)	Import
				Consumption
	Food Chemical Codex (FCC)	Others (resale) & Food	RoW	Stocks

DRIVERS	BARRIERS
Population Growth	Growth of Renewable Diesel (HVO)
Environmental Targets / Circularity	Excess dependency on Biodiesel
Biodiesel demand growth (FAME)	
Refraining from edible feedstocks and push for waste-based feedstock for technical applications	

FIGURE 1 – WASTE-BASED GLYCEROL MARKET' MAIN VARIABLES, DRIVERS AND BARRIERS.

Glycerol: market size and forecast

Since the early 2000s, the glycerol demand-supply balance has been disrupted by the biodiesel market growth, influencing prices, and leading them to a further decrease.

Biodiesel (FAME) is in fact the main source of glycerol, reportedly accounting for 59.5% of the global glycerol market size[6], a share destined to grow in the coming years (the biodiesel market will be analysed in the next section). In the EU this share is still higher, exceeding 80% in 2020. Other glycerol sources can be fatty acids, fatty alcohols and soaps (Figure 2).

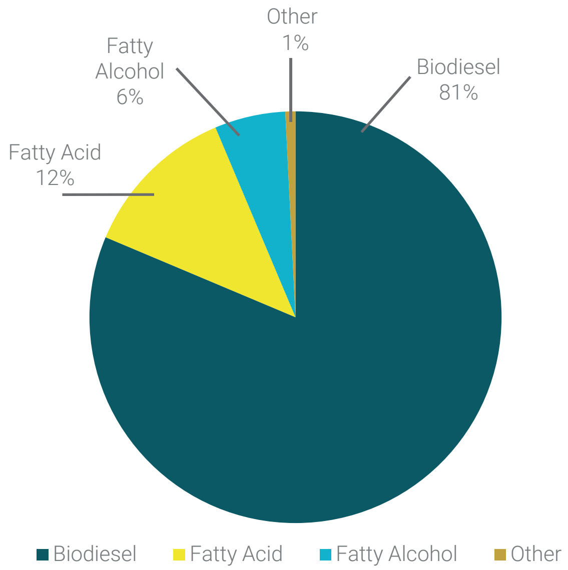


FIGURE 2 – EU GLYCEROL PRODUCTION 2020 BY SOURCE

The global glycerol market is expected to grow at a CAGR of 6.1%, moving from a value of € 2.2 billion in 2021 to an estimated value of €2.92 billion in 2026 (more than 3,000 Mtons). By geography the sector is dominated by the Asia Pacific countries, while Europe represents the second-largest regional market, with around 30% of the market share.

Although the COVID pandemic has somehow put established trends on hold, it can be argued that these changes are temporary. In this perspective, the EU has a strong export tradition, with balanced prices (ca. 280€ per metric ton[5]), while China and North America have been importing for years[5].

Biodiesel and renewable diesel: market size and production capacity

Europe dominates the global biodiesel market with about 50% of market share.

The **global biodiesel market** is expected to reach €37.8 billion by 2028 from €28.6 billion in 2022, registering a CAGR of 4.6% in the forecast period[7]. Under a more conservative scenario, the market is projected to grow at a CAGR of 1.5% from a value of €20.98 billion in 2022 to a value of €22.93 billion in 2028[8].

In line with this trend, **biodiesel is today the most important biofuel in Europe**, representing - on an energy basis - **about 75% of the total transport biofuels market.** Among the reasons contributing to the expansion of this market in Europe, there is the fact that biodiesel has been demonstrated to have significant environmental benefits in terms of decreased global warming impacts, reduced emissions, greater energy independence and a positive impact on agriculture, where the use of biodiesel leads to 65%-90% reduction of CO_2 emissions compared to conventional diesel[9].

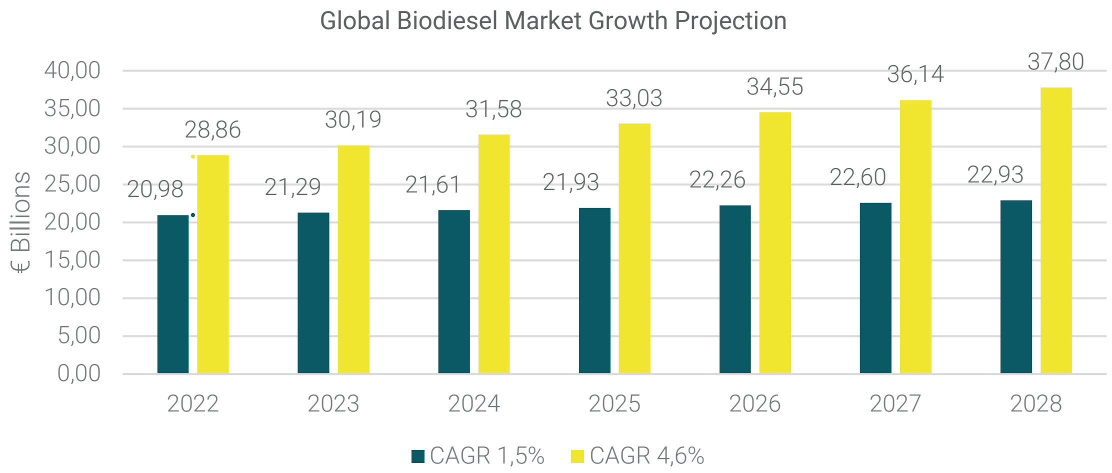


FIGURE 3 - GLOBAL BIODIESEL MARKET GROWTH PROJECTIONS

Table 1 summarizes the **EU biodiesel production and consumption** considering both the traditional biodiesel (fatty acid methyl ester, FAME) and the renewable diesel (hydrogenated vegetable oil, HVO)[10]: it should be noted that glycerol is a by-product of FAME, while HVO produces propane: therefore, HVO's possible rise is a barrier limiting the production of cheap waste-based glycerol. Considering the numbers, and assuming that for every 10 kg of biodiesel produced, approximately 1 kg of crude glycerol is created[11], the **European biodiesel sectors produce annually about 1.01 Mton of crude glycerol.**

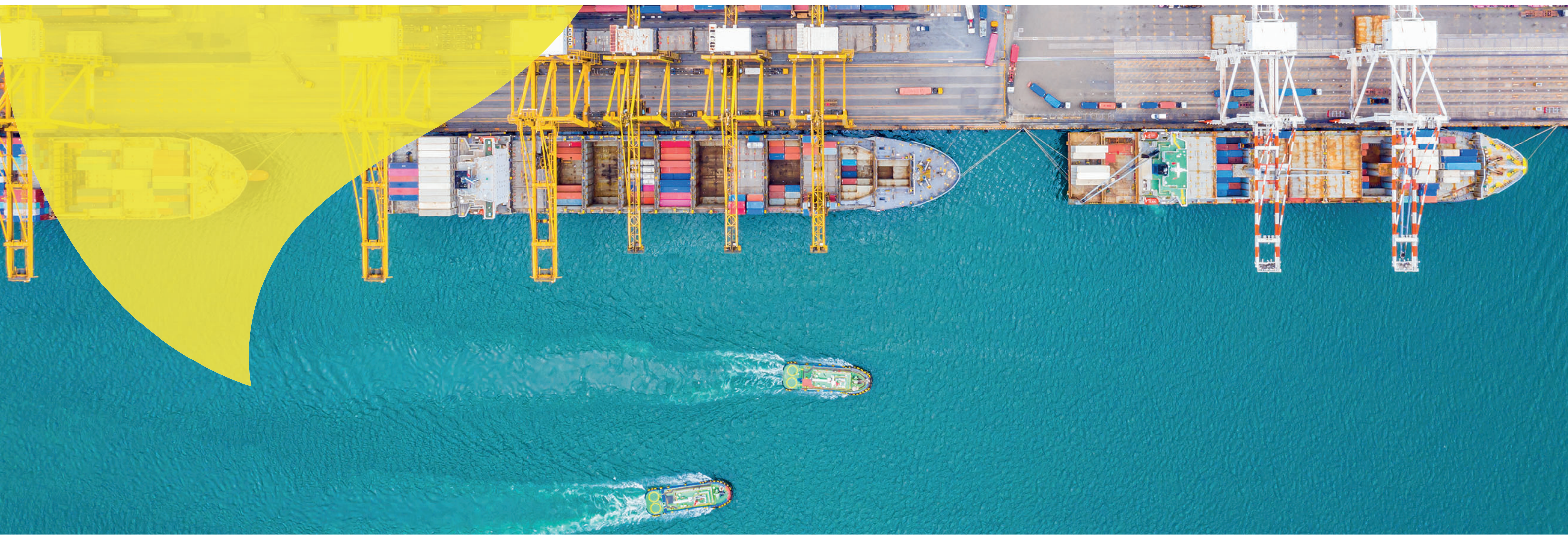
FAME and HVO biodiesel (Million litres)				
	2018	2019	2020	2021
Beginning stocks	670	930	750	730
Production	14,946	15,781	15,534	16,110
- FAME Production	12,241	12,843	11,924	12,330
- HVO production	2,705	2,938	3,610	3,780
Imports	3,781	3,613	3,106	3,100
Exports	645	759	465	530
Consumption	17,822	18,815	18,195	18,660
Ending stocks	930	750	730	750
Production Capacity, Biodiesel (FAME) (Million Litres)				
Number of biorefineries	186	186	187	187
Nameplate capacity	21,030	21,130	21,230	21,230
Capacity use	58.2%	60.8%	56.2%	58.1%
Production Capacity, Renewable Diesel (HVO) (Million Litres)				
Number of biorefineries	14	15	15	15
Nameplate capacity	3,610	5,210	5,210	5,280
Capacity use	74.9%	56.4%	69.3%	71.6%
Feedstock Use for Biodiesel + Renewable Diesel (HVO) (1,000 MT)				
Rapeseed oil	6,000	6,000	5,500	5,800
UCO (Used Cooking Oil)	2,800	3,150	3,300	3,400
Palm oil	2,500	2,650	2,650	2,630
Animal fats	870	900	1,150	1,150
Soybean oil	900	1,000	1,000	950
Sunflower oil	247	265	245	230
Other (pine oil/tall oil/fatty acids)	627	768	662	675

TABLE 1 – EU BIODIESEL IN FIGURES

Main EU biodiesel producers: In the period from 2018 to 2021, **Germany was the largest producer of FAME in Europe.** From 2019 to 2020, the total European production has been relatively constant, with an average year production of 12.3 billion litres. **Concerning HVO, the Netherlands resulted the largest producer in Europe** with a constant production level of around 1.2 billion litres per year. From 2019 to 2020, an increase in total HVO biodiesel production of 20% was recorded. This trend is mainly due to higher production levels in France and Italy, which increased by 39% and 44% respectively.

EU FAME Producers (Million litres)	2018	2019	2020	2021
Germany	3,799	4,070	3,862	4,100
France	2,806	2,556	2,045	2,045
Spain	2,008	1,835	1,550	1,450
Netherlands	1,010	1,081	1,102	1,100
Poland	1,001	1,091	1,081	1,090
Italy	511	616	616	620
United Kingdom	500	620	550	570
Other	606	974	1118	1,335
Total	**12,241**	**12,843**	**11,924**	**12,330**
EU HVO Producers (Million litres)	**2018**	**2019**	**2020**	**2021**
Netherlands	1,218	1,218	1,218	1,220
Italy	323	397	910	910
France	128	150	385	500
Spain	482	549	480	460
Finland	354	424	423	420
Sweden	160	160	160	230
Portugal	37	37	32	32
Czech Republic	3	3	3	3
Total	**2,705**	**2,938**	**3,610**	**3,780**

TABLE 2 – EU FAME AND HVO MAIN PRODUCERS



Demand analysis: the aviation and maritime biofuel market

Biofuel market value and forecast

Biofuels are energy carriers that store the energy derived from biomass. They can be divided into *i)* **first-generation biofuels**, produced from food crops such as sugar cane and rapeseed. They include bioethanol (made from sugars and starch) and biodiesel (made from vegetable oil); *ii)* **second-generation biofuels,** derived from non-food plant matter such as crop residues and agricultural or municipal wastes. They include bioethanol made from cellulosic materials such as straw or wood.

The global biofuels market is expected to rise from its initial value of €126 billion in 2020 to an estimated value of €229.8 billion in 2028, by registering a CAGR of 7.8% in the considered period [12,13,14]

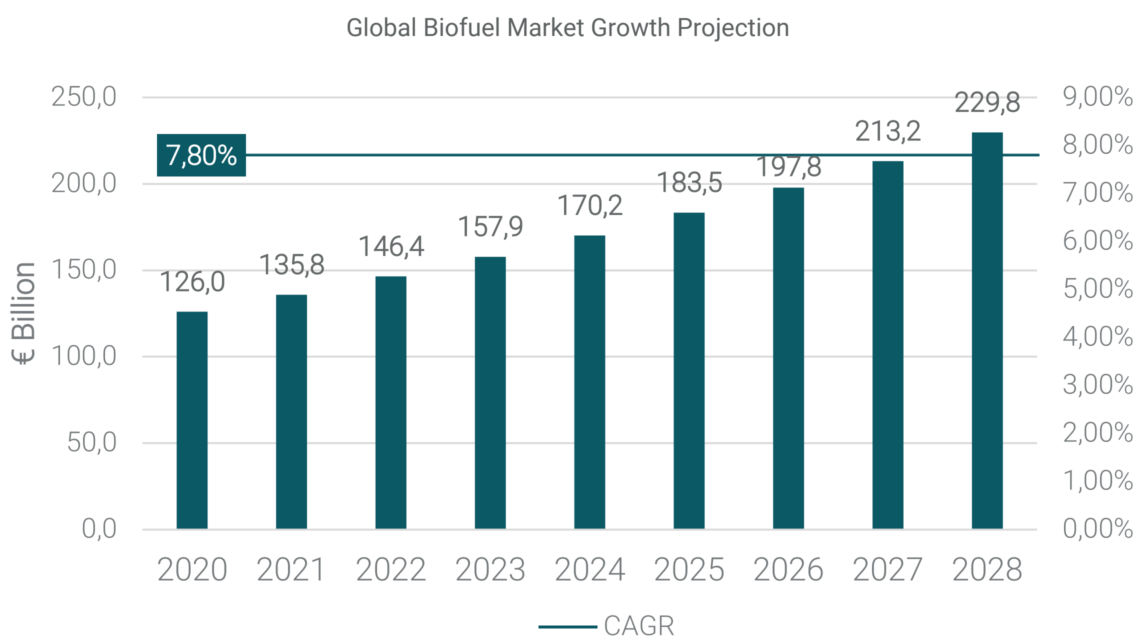


FIGURE 4 - GLOBAL BIOFUEL MARKET GROWTH PROJECTIONS

Regional analyses have shown that the **North American biofuel market,** growing at a CAGR of 7.8%, will increase from a value of € 61.2 billion in 2020 to € 111.7 billion in 2028, accounting for a market share of **48.6%. The Asia Pacific region,** counting on a market share of 8.3%, will go from a value of €10.46 billion in 2020 to a value of €19 billion in 2028. Other regions that will experience interesting growth in the next years include **Brazil** and the **European Union.**

Liquid biofuels offer an alternative for all types of internal combustion engines running on gasoline, diesel or kerosene, including for use in passenger vehicles, trucks, ships and airplanes. Liquid biofuels, including both conventional and advanced forms of ethanol and biodiesel, could account for 10% of transport sector energy use by 2030.

Analysing the specific market segment of the liquid biofuels for transport, a similar trend to the general biofuel market emerges. According to different analysis, the **global liquid biofuels market is projected to grow at a CAGR of 5.2%** from a value of €58 billion in 2020 to €83 billion in 2027 [15,16,17]. Similar to the global biofuel market, also in this case the **United States** together with China dominate – and are expected to continue dominating - the liquid biofuels market, displaying an estimated CAGR of 5.6% and 8.3%, respectively. In detail, the value of the **US liquid biofuels market** is expected to increase from a value of €16.61 billion in 2021 to a value of €23.03 billion in 2027, increasing its current market share at global level of **27% to 28%** in 2027. The Chinese market will grow from a value of €10.4 billion in 2021 to a value of €17.27 billion in 2027, thereby increasing its market share from **17% to 21%**[15].

As described above, **advanced biofuels** (or second-generation biofuels) differ from conventional biofuels since they are manufactured from various types of **non-food biomass.** Sustainable feedstocks used for producing advanced biofuels include crops grown on marginal land (that do not compete directly with food crops for land or cause indirect Land Use Change), waste and residues (e.g., agricultural, forestry, Municipal Solid Waste and other organic wastes and residues), novel feedstocks (e.g., aquatic plants, microalgae and other microbial biomass)[18].

The Global Advanced Biofuels market is projected to grow at a **CAGR of 38.5%** in the coming years[19]. This segment will increase from a value of **€38.8 billion** in 2021 to an estimated value of **€142 billion in 2025.**

Finally, **Sustainable Aviation Fuel Market (SAF)** is the term used within the aviation industry to refer to an aviation fuel that is not derived from fossil raw materials[20].

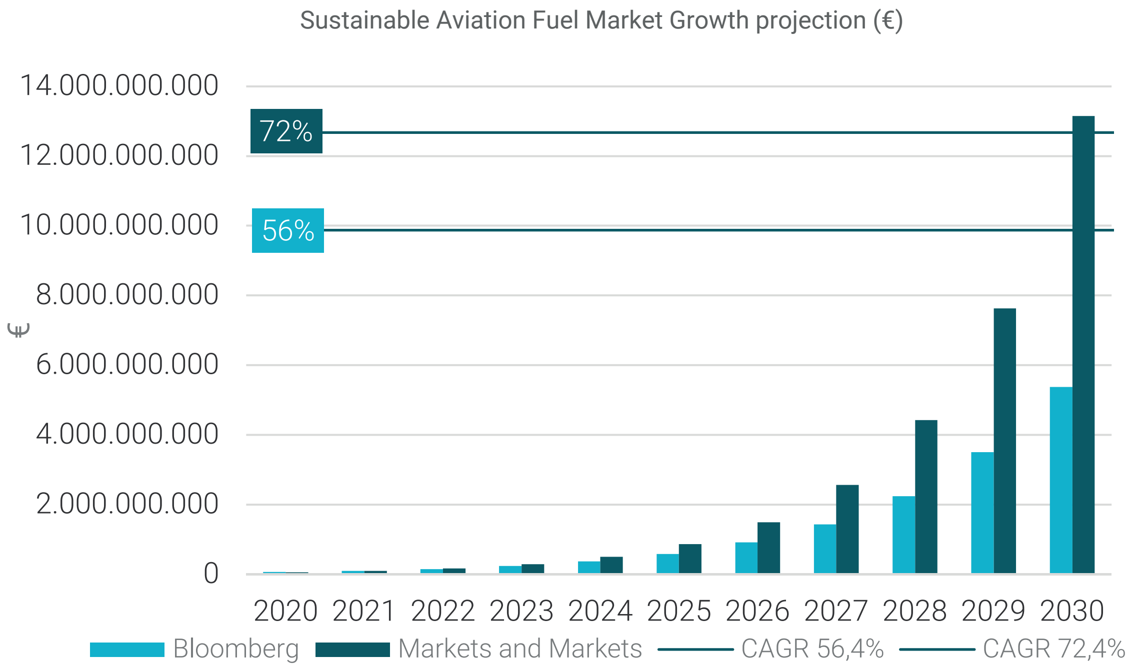


FIGURE 5 - SAF MARKET GROWTH PROJECTIONS

Under a more pessimistic scenario, the **SAF market** will grow at a **CAGR of 56.4%** from a value of €62.5 million in 2020 to a value of €5.4 billion in 2030. In contrast, under a more optimistic scenario, the market will grow at a **CAGR of 72.4%** from a value of €56.6 million in 2020 to a value of €13.1 billion in 2030.

Europe is one of the main producers of SAF. Countries such as Netherlands, England and Norway make significant investments in infrastructure to produce bio-jet fuel [21].

Key players

Looking at industry, POET LLC (US), Algenol (US), Archer Daniels Midland Company (US), Bangchak Corporation Public Company Limited (Thailand), Gevo, Inc. (U.S.), Abengoa Bioenergy S.A. (Spain), DuPont (US), GranBio (Brazil) **are among the players leading the global biofuel market (including liquid fuels and advanced fuels)** (Figure 6).

At **European level,** the main players are UPM-Kymmene Oyj (Finland), Green Fuel Nordic Oy (Finland), Svenska Cellulosa AB (Sweden), Preem AB (Sweden), SunPine AB (Sweden), Galp Energia (Portugal), Biomethanol Chemie Nederland BV (Netherland), Borregaard ASA (Norway), among others.

Finally, looking at **the specific SAF segment,** Gevo Inc. (US), Neste (Finland), Fulcrum Bioenergy (US), SkyNRG (Netherlands), Aemetis Inc. (US), Velocys (UK) and Red Rock Biofuels are leading players on the market.

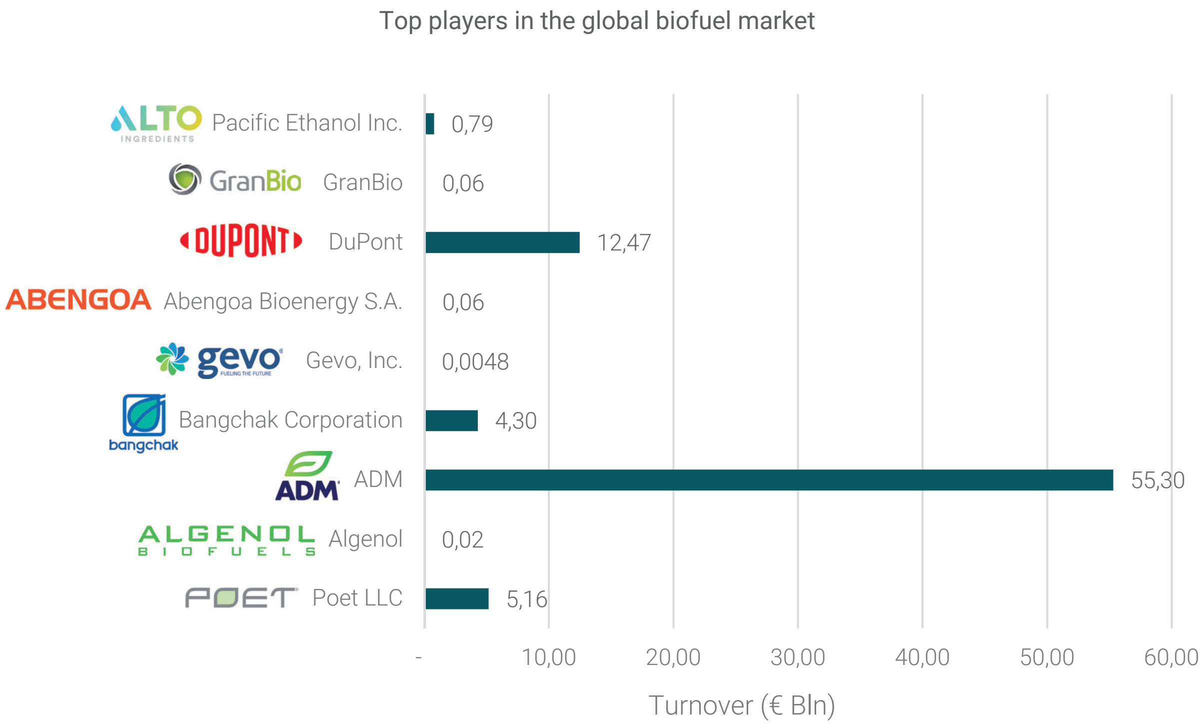


FIGURE 6 – RELEVANT PLAYERS IN THE BIOFUEL MARKET AND TOTAL TURNOVER

Biofuel future production and consumption

What is the Sustainable Development Scenario (SDS)?

The Sustainable Development Scenario (SDS) is a scenario outlined by the International Energy Agency (IEA) to examine future energy trends relying on the World Energy Model (WEM) – a large-scale simulation model designed to replicate how energy markets' function.
The SDS is based on a surge in clean energy policies and investment that puts the energy system on track for key Sustainable Development Goals (SDGs) and it specifies a pathway aiming at ensuring universal access to affordable, reliable, sustainable and modern energy services by 2030 (SDG 7) substantially reducing air pollution (SDG 3.9); and taking effective action to combat climate change (SDG 13).

According to the IEA, the **global biofuel production for transport reached 96 Mtoe in 2019**, with an expected 3% annual production growth in the next years. However, to align with the SDS a 10% of output growth is needed, meaning that the **estimated biofuels production growth falls short of the sustained output growth per year needed until 2030** to be on track with the SDS.

This production shortage is particularly relevant in Europe, while other regions, such as South-East Asia, China and Brazil are better positioned to keep pace with the production levels required by the SDS in 2030.

In fact, as also reported in Figure 7 in Europe the biofuel annual production growth is 0.5% between 2019 and 2025. However, according to the SDS, **the annual EU biofuel consumption should be about 85 billion litres by 2030** and, to meet this goal, the production needs to grow with a CAGR of 9% in 2019-2030 period. This suggests that with the actual biofuels annual production in Europe, in the 2030 it is expected a gap of more than 30 billion litres per year between the biofuel demands (under a sustainable scenario) and the European production.

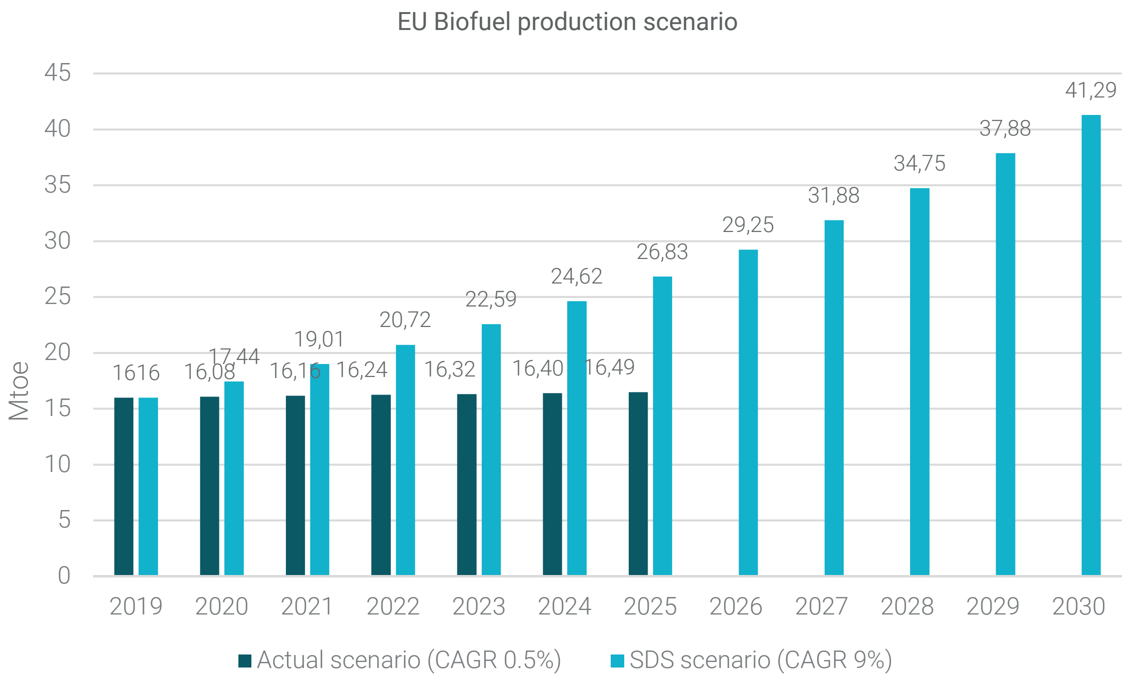


FIGURE 7 – EUROPEAN ACTUAL PRODUCTION VS SDS

According to the IEA data, the **biofuel consumption in the transportation sector will increase over the 2015-2030 period.** It is worth mentioning here that, assuming a total global consumption of 300 Mtoe biofuels for transport in 2030, the **consumption's share of biofuels used for transport from the aviation and maritime sectors is expected to increase** (reaching the share of 10.3% and 5% in 2030, respectively) while the share of road freight and passenger vehicles will slightly decrease in the estimated scenario[22]. Assuming a similar share for the European biofuel consumption, in the SDS the annual EU aviation and maritime biofuel consumption will be **13 billion litres by 2030.**

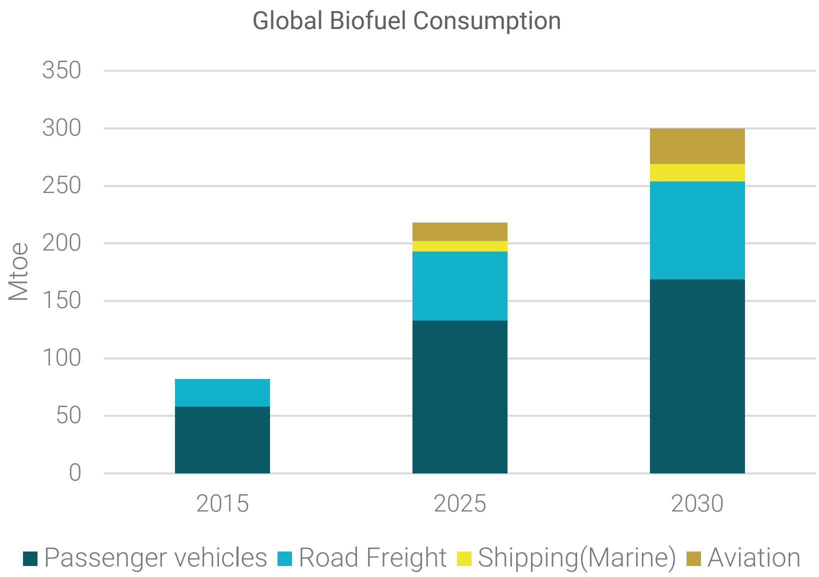


FIGURE 8 - GLOBAL BIOFUEL CONSUMPTION BREAKDOWN PER SUBSECTOR (SOURCE IEA)

Considering the **types of liquid biofuels**, the production of ethanol followed by biodiesel dominate the market. The United States and Brazil are among the main producers of ethanol while Europe, on the other hand, is the main producer and consumer of biodiesel on a global scale.

Biofuels in the aviation and maritime sectors: key factors and economic analysis

Currently, the consumption of biofuels in aviation and shipping is still very limited compared to other transport sectors. However, the regulatory environment aimed at reducing GHG emissions is expected to act as a main driver for **increasing the production and demand for sustainable fuels in aviation and maritime sectors** both at European and global level.

Biofuels in Aviation – Key facts and regulations

Globally, various technologies for production of sustainable biofuels for aviation are currently being developed by research organisations, fuel producers and aircraft manufactures. In the short term, **hydro-processed esters and fatty acids (HEFA) appears to be the most promising alternative** to supply significant amounts of biofuel for aviation, while in the medium term, **drop-in FT-fuels** are expected to be highly promising.

In order to be used in commercial flights, a sustainable aviation fuel (SAF) has to comply with ASTM standard, such as the ASTM D4054. As of October 2021, the following aviation biofuel production pathways are approved by the standard[23]:

Name	Technology	Projects / Commercialisation
FT	Paraffinic kerosene synthesized from coal, natural gas and biomass through Fischer-Tropsch hydro-processing (50% blending rate)	SG Preston, Syntroleum, Shell, Fulcrum Bioenergy, Sasol, Red Rock Biofuels, Kaidi
HEFA	Paraffinic kerosene synthesized from bio-oils, animal fats and recycled oils through esters and fatty acids hydro-processing (50% blending rate)	Dynamic Fuels, Honeywell UOP, World Energy, EERC, Neste Oil
SIP	Iso-paraffins synthesized from biomass used for sugar production through sugars fermentation hydro-processing (10% blending rate)	Amyris, Total
FT-SKA	Kerosene synthesized from coal, natural gas and biomass through alkylation of light aromatics (50% blending rate)	Sasol
ATJ-SPK	Ket synthetic paraffinic kerosene produced from ethanolic/isobutanolic biomass (50% blending rate)	Byogy Renewables, Cobalt Biofuels, Honeywell UOP, Swedish BioFuels, Gevo, LanzaTech
CHJ	Jet fuel produced from triglycerides (e.g., soybean oil, jatropha oil, camelina oil, carinata oil, tung oil) through catalytic hydro-thermolysis (50% blending rate)	ARA
HC-HEFA-SPK	Synthesized paraffinic kerosene produced from algal biomass through esters and fatty acids hydrocarbon hydro-processing (10% blending rate)	IHI
Co-processed HEFA	Co-hydroprocessing of esters and fatty acids from fats, oils, and greases mixed with petroleum in a conventional petroleum refinery (5% blending rate)	
Co-processed FT	Co-hydroprocessing of Fischer-Tropsch hydrocarbons with petroleum in a conventional petroleum refinery (5% blending rate)	Fulcrum Bioenergy

TABLE 3 – ASTM CERTIFIED BIOFUELS

The **estimated current production of sustainable aviation fuels is around 0.05%** of current aviation fuel consumption, where the largest share is HEFA-SPK based on fats and oils[24].

SAFs are recognised to be essential to achieve climate objectives by 2050. These fuels are estimated to **generate 80% less carbon emissions** than conventional kerosene. According to the International Air Transport Association (IATA), in the Fly Net Zero Scenario – a commitment of airlines to achieve net zero carbon by 2050 - SAFs can account for the **65% elimination of emissions at the source** to achieve net zero carbon in aviation[25].

Legal and political framework for sustainable aviation fuels: At present, there is still no obligation for the aviation sector to use SAF. However, on 14th July 2021, the EC published a proposal for the ReFuelEU Aviation directive (part of the *Fit for 55 Package*) that will require aviation fuel suppliers in all EU member states to provide **2% SAF in 2025.** According to the proposal, such a mandatory share will increase in 5-year steps to **63% SAF in 2050.**

Other policies or initiatives at EU level that are expected to incentivise the production and use of SAF are:

- The International Civil Aviation Organization (ICAO) has developed a *Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*, setting the target of 50% GHG emission reduction until 2050 (compared to 2005).
- The High-Level Group on Aviation Research sets ambitious goals including a 75% reduction in CO_2 emissions and a 90% reduction in NO_x emissions per passenger kilometre in 2050.
- IATA is committed to achieve carbon-neutral growth starting in 2020 and a 50% overall CO_2 emissions reduction by 2050.

Biofuels in maritime sector – Key facts and regulations

The maritime sector is still anchored to the use of traditional fuels (i.e., HFO and MDO) and utilisation of biofuels is very limited at global level. In the EU, **currently no significant consumption of biofuels for shipping takes place.**

A number of different fuel types are being discussed as potential replacements for fossil fuels, including green and blue hydrogen, ammonia, methanol and biogas. However, the supply infrastructure and technological readiness for these fuels remain to be developed. Several biofuel alternatives are already available today, and more are expected to become available in the near future. Among the most promising biofuels, **fatty acid methyl ester (FAME) and hydrotreated vegetable oil (HVO, or renewable biodiesel),** are believed to have the greatest potential for application in marine diesel engines[26].

The main features of these biofuels are:

Name	Technology
FAME	Mono-alkyl ester production from lipids, such as vegetable oils (e.g., palm oil, soybean oil, rapeseed oil), animal fats (e.g., tallow oil) and used exhausted cooking oils, (20 - 50% blending rate) through transesterification, in which triglyceride from the feedstock reacts with methanol in the presence of a catalyst, forming the mixture of fatty acid esters and glycerol
HVO	Paraffinic hydrocarbons production from lipids (like FAME and/or obtained from residual crops and industrial waste) through hydrocracking.

TABLE 4 – BIODIESEL FOR MARITIME SECTOR

FAME and HVO are often considered drop-in fuels. However, special attention should be paid to operation on board, including fuel storage and treatment.

Legal and political framework for sustainable maritime fuels: Similarly to the aviation sectors, here there is still no obligation for using renewable fuels. However, as part of the *Fit for 55 Package*, the EC recently launched the *FuelEU maritime*, a proposed regulation introducing increasingly stringent limits on carbon intensity of the energy used by vessels from 2025, which should oblige them to use alternative fuels.

Other policies or initiatives at EU level that are expected to incentivise the production and use of alternative fuels and decarbonise shipping sector:

- International Maritime Organization (IMO) has agreed to adopt a strategy to reduce CO_2 emissions related to shipping by 40% before 2030 and to reduce all greenhouse gas (GHG) emissions by 50% before 2050 (compared to 2008).
- The 2020 Sulphur cap introduced by IMO mandated that by 2020 no ships will be allowed to sail elsewhere if using a fuel with more than 0.5% percentage of sulphur.
- As part of the *Fit for 55 Package*, the EC proposed to include the maritime sector in the Emissions Trading System (ETS) system.

Aviation and Maritime biofuels – Current costs of biofuels vs standard fuels

Biofuel production for aviation and maritime applications is technically viable, but **the availability of suitable fuels is low.** In addition, uptake is constrained by **high cost of technological development and production** that are higher than fossil fuels at current oil prices, especially since policy support is less widespread than for road transport.

In the following the biofuels costs are compared with the traditional fuels used in aviation and shipping sectors. In both these subsectors, **the cost of biofuels is higher than conventional fuels**. However, current biofuel consumption is minimal in both aviation and maritime, so numerous efforts will be required both by governments and by companies operating in this sector to be able to make biofuels more competitive in terms of price and to give stringent regulations about their adoption in maritime and aviation.

Fuel Type	Cost (€/litre)
Aviation[1]	
Conventional Jet Fuel	0.43
HEFA (from palm oil) – renewable biodiesel	1.00
HEFA (from UCO) – renewable biodiesel	0.86 – 1.09
HEFA (from tallow) – renewable biodiesel	1.02
FT - Fischer-Tropsch jet fuel (from natural gas and coal)	0.88
FT – Fischer-Tropsch jet fuel (from forest wood)	1.32 – 1.77
ATJ – Alcohol to Jet fuel (from forest residues and wheat straw)	2.38
Jet fuel from pyrolysis (from forest residues and wheat straw)	1.27
Jet fuel from HTL (from forest residues and wheat straw)	0.89
Jet fuel from DSHC (from forest residues and wheat straw)	4.60
Marine[2]	
HFO - Heavy Fuel Oil	0.21
MDO – Marine Diesel Oil	0.35
FAME (Fatty Acid Methyl Ester) – traditional biodiesel	0.75
HVO – renewable biodiesel	0.39

TABLE 5 – BIOFUELS COSTS COMPARED WITH CONVENTIONAL JET AND MARITIME FUELS

[1] ETIP Bioenergy: Biofuels for aviation

[1] IEA Bioenergy: Biofuels for the marine shipping sector

Focusing on the aviation sector, the table above shows that conventional jet fuels are cheaper than the biofuel HEFA. This is because HEFA refining requires more severe processing that increases the final cost and reduces yields per tonne of feedstocks by 5-10%. Similar features and constraints characterise the other types of biofuels. Such an increase of the production costs is one of the problems that has slowed down the growth of biofuel adoption in the aviation[29]. Finally, the capital cost needed for each technology mentioned to produce jet biofuel is summarized in the table below, considering an assumed output of 500 tons of fuel per day.

Technology	Capital cost to produce 500 tons of fuel per day
HEFA	€ 200–644 millions
FT	€ 327–1,186 millions
Pyrolysis & upgrading	€156–482 millions
HTL (Hydrothermal liquefaction) & upgrading	€ 273–513 millions
ATJ (from ethanol; excludes ethanol production)	€ 68–72 millions
Ethanol production from agricultural residues	€ 215–426 millions
Advanced fermentation of sugars to hydrocarbons	€ 292 millions
Sugar extraction from agricultural residues	€ 206 millions

TABLE 6 – CAPITAL COST NEEDED TO PRODUCE JET BIOFUEL, BY TECHNOLOGY

INNOVATION TRENDS AND LANDSCAPE

R&D trends in the biofuel development field

Analysis of the innovation landscape: information and factors considered

Analysis of the innovation landscape: relevant sources and selection factors

R&D projects and innovators

A total number of **30 national, international and European projects (from 2015 to 2021)** were identified and selected in the field biofuel sector related to different topics *i)* the application of gas-solid reforming processing, Fisher-Tropsch process and use of advanced catalysts for fuels synthesis; *ii)* utilisation of sustainable biomass for advanced biofuels, avoiding competition with food resources *iii)* production of transport fuels for aviation and maritime sectors.

We refer to the key experts identified through this analysis as "innovators"

Patents and investors on IP

Complementing the analysis of the innovation trends concerning the advanced biofuels processes, a patent analysis has been carried out identifying a total **151 international patents** published from 2015 to date. The selection criteria have been: i) Feedstock used (crude glycerol), ii) Products (syngas, kerosene, synthetic paraffine kerosene, FT-SPK), iii) Process (Fischer-Tropsch, gasification, chemical looping, autothermal reforming), iv) Application sector (maritime, aviation, others) and v) used catalysts. **10 patents** have been then selected as most relevant ones.

Since patenting is a type of investment in new technologies and it defines the interest into a specific market, in this work we refer to patent owners as "investors on IP".

Main findings

Germany is the most active European country for R&D in the advanced biofuel sector.

Germany is ranked as the top country in terms of participation in publicly funded R&D, having participated to 15 funded projects with, in total, 35 participants. The UK follows with 13 projects and Norway with 11 projects. Considering the number or organisations participating in the selected projects, Netherlands comes right after Germany having 26 participating organisations, followed by UK with 14 participants.

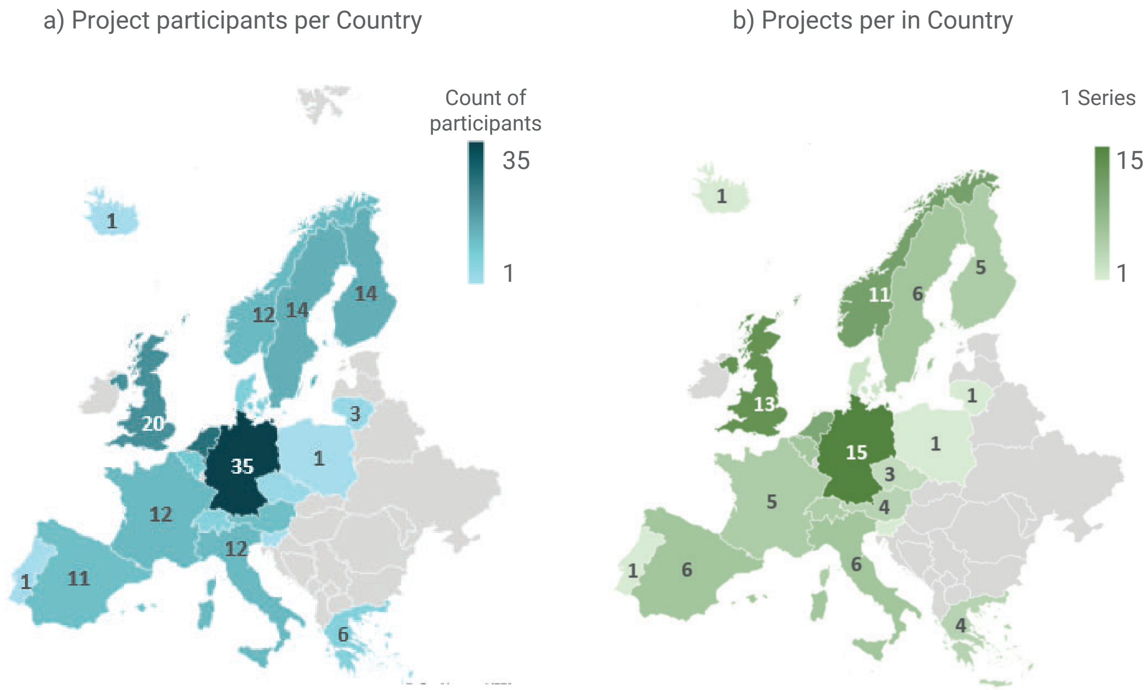


FIGURE 9 – A) NUMBER OF EU FUNDED R&D PROJECTS PER EUROPEAN COUNTRY; B) NUMBER OF PROJECT PARTICIPANTS HOME COUNTRY

The global patent landscape is dominated by the USA.

At international level, **USA emerges as top applicant country (77 patents)**, followed by Japan and China. At European level, **France, Netherland**, and **UK** are the most active countries for IP protection.

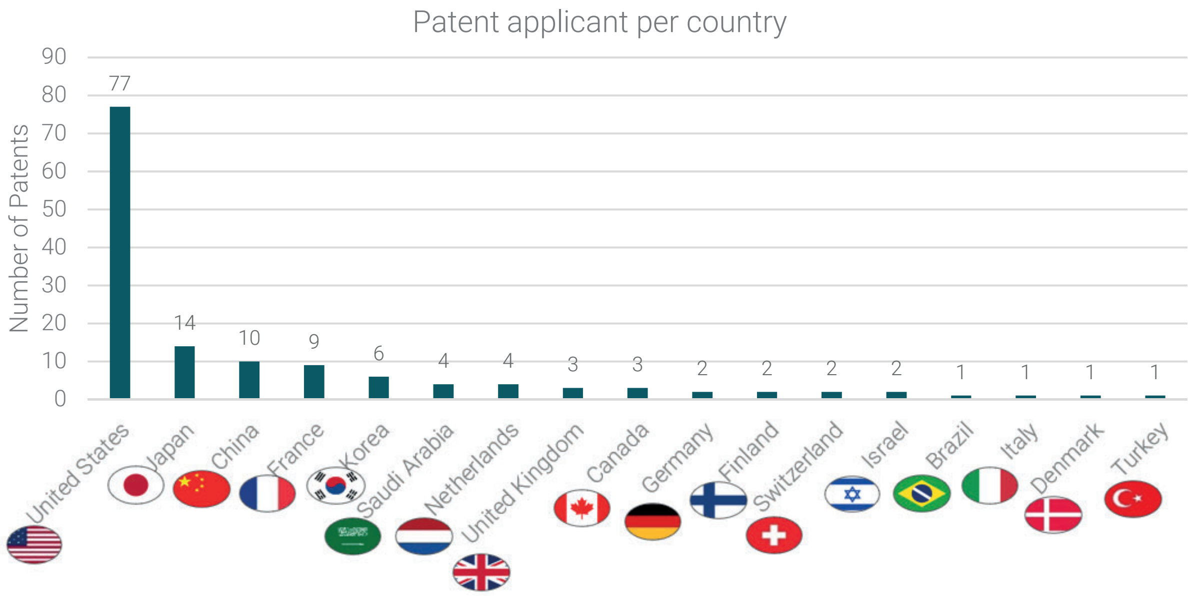


FIGURE 10 – GEOGRAPHICAL DISTRIBUTION OF IP OWNERS IN THE ADVANCED BIOFUEL SECTOR ANALYSED IN THIS STUDY

Industries play a leading role in publicly funded R&D in new biofuels for maritime and aviation.

The analysis of the relevant projects features **169 different organizations**, of which **industries represent 45%**, while **together Universities and RTOs constitute 51% of the participants** (Figure 11). Interestingly, it should be noticed that in general industry represents a lower share in public funded R&D projects accounting for about 35% of total participants, while in the biofuel domain the SMEs and Large enterprises participating in funded projects are nearly half of total. This suggests that industry has a strong stake in R&D in activities for biofuels development compared to other technological domains, but the collaboration with RTOs and universities remains crucial.

IP owners of biofuels processes technologies and related domains are mostly industrial organisations.

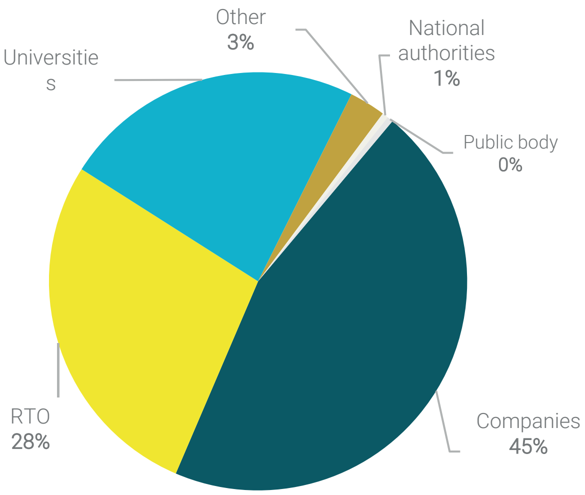
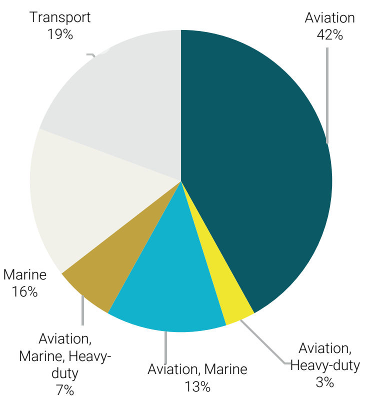


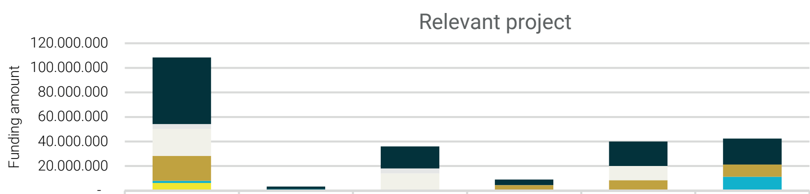
FIGURE 11 – TYPE OF ORGANISATIONS PARTICIPATING IN THE SELECTED R&D PROJECTS

When protected IP in this domain is considered, industries play a leading role. 71% of the patents identified in this study have SMEs or Large Industries as applicants, while the remaining 29% are from research organisations.

The R&D focused on the development of sustainable biofuels for the aviation sector attracted about €78 million of public funding in the last six years.

From the technical and economic analysis of the projects selected for this study, it emerges that the aviation sector is the most active in R&D, having 13 active projects and receiving about € 54 M for projects focusing only on aviation fuels and about € 78 M considering all projects that include the aviation among the application sectors. The maritime sector attracted a somewhat lower but still significant funding amount (about € 20 M) with 5 active projects (Figure 12).





	Aviation	Aviation, Heavy-duty	Aviation, Marine	Aviation, Marine, Heavy-duty	Marine	Transport
Grand Total	54.216.630	1.647.996	17.990.910	4.496.755	19.986.887	21.199.580
2021	3.994.322		3.993.006			
2020	21.991.725		13.997.904	7.210	11.548.777	
2018	20.255.650			4.489.545	8.438.110	9.948.146
2017	1.846.318					10.993.647
2016	6.128.615					257.787
2015		1.647.996				

FIGURE 12 – APPLICATION SECTOR IN THE PROJECTS AND FUNDING AMOUNT PER YEAR

R&D on advanced biofuels for aviation and maritime sectors has not reached yet a mature stage. Gasification and FT processing are the most promising technologies currently under development.

The heatmap in Figure 13 confirms the high interest towards the development of fuels for aviation and maritime application, summarising the major R&D trends in terms of advanced biofuel production technologies, maturity level as well as application areas. **Gasification and FT are the most investigated** technologies, especially for aviation and other transport fuels. More than 80% of funded R&D in the domain are targeted at low-medium TRL levels, focussing on **validation at lab-scale or relevant environment, while the demonstration and qualification at industrial level is still limited**. Finally, most of the advanced fuels production systems in the analysed R&D projects entail the **valorisation of lignocellulose biomass**, for both biofuels and biodiesel, but other types of sustainable biomasses are also considered.

Application area		Biofuels production technology and maturity level: Type of feedstock – Lignocellulosic biomass	Municipal waste	Algae	CO2	Other type	Technology – Gasification	Fischer-Tropsch	Pyrolysis	Use of catalysts	Other	TRL – Low - Medium	Medium - High
End product	Biofuel (not specified)	12	0	1	1	4	6	4	2	3	7	10	6
	Bio-ethanol	1	0	2	0	0	1	0	0	1	1	2	0
	Biodiesel	4	1	0	0	1	3	2	0	2	2	5	1
	Sustainable Kerosene	0	0	0	1	0	0	1	0	0	0	1	0
	Fuel intermediate	2	0	0	0	1	1	1	0	0	1	2	0
	Methanol	0	0	0	0	1	0	0	0	0	1	0	1
	TAGs	0	0	0	0	1	1	0	0	0	1	1	0
	Bio Heavy Fuel Oil	1	0	0	0	0	0	0	0	0	1	1	0
Sector	Aviation	9	1	2	1	3	6	4	1	3	3	12	2
	Maritime	4	1	0	1	4	1	0	1	1	1	7	2
	Heavy duty	2	0	0	0	0	1	1	0	1	0	3	0
	Transport (other)	3	1	0	0	1	4	4	0	2	0	2	3

FIGURE 13 – R&D HEATMAP BASED ON THE SELECTED FUNDED PROJECTS ON ADVANCED BIOFUELS

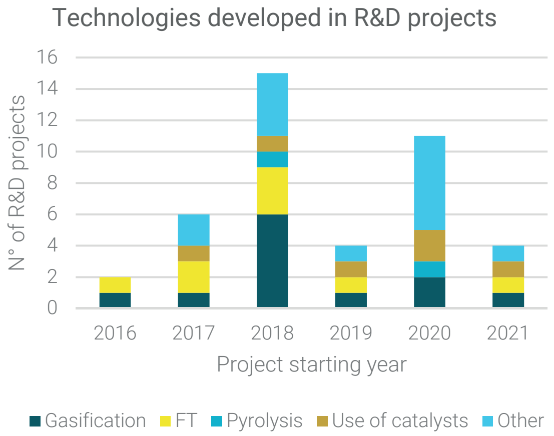


FIGURE 14 - TECHNOLOGIES DEVELOPED IN THE SELECTED R&D PROJECT PER YEAR

The analysis indicate an increasing R&D trend in **gasification and FT technologies until 2018**, R&D **on catalysts for advanced biofuels received constant attention over the the last five years**, from 2017 to 2021.

IP-covered technologies developed in the last years mostly focus on the preparation and use of catalysts for fuels production.

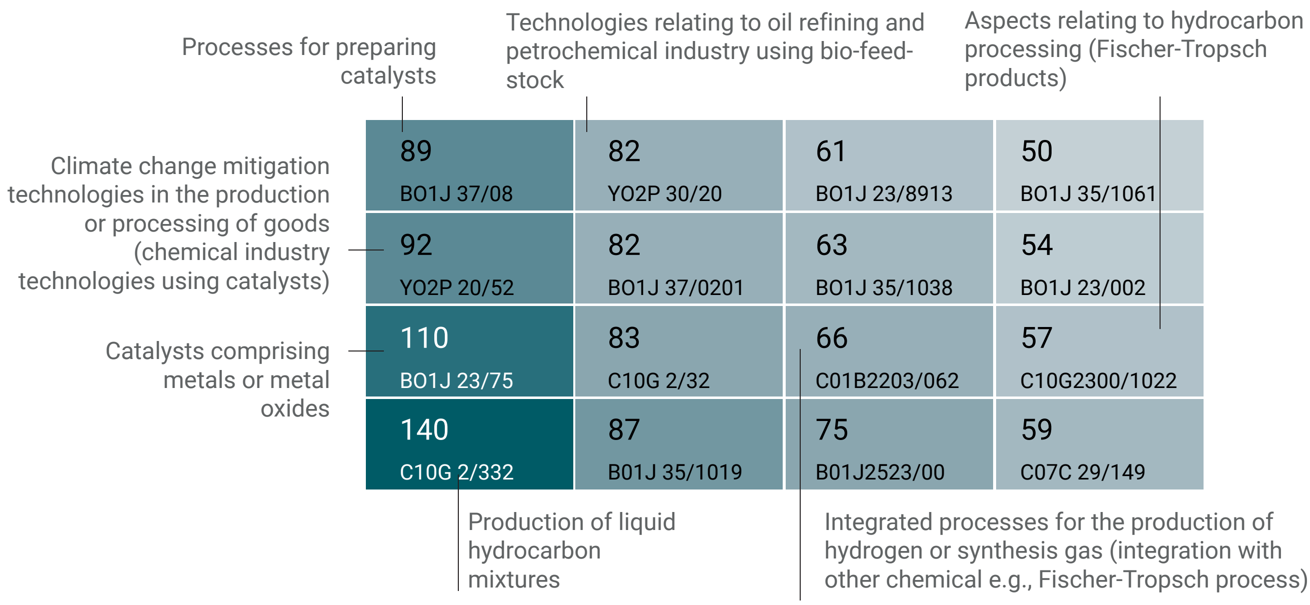


FIGURE 15 – MOST RELEVANT CPC CODES BASED ON THE PATENTS ANALYSIS

The analysis of the R&D trends is complemented by the heatmap of the most relevant Cooperative Patent Classification (CPC) emerged from the patent analysis, that define the category to which the innovations of the selected patents belong. As detailed in Figure 15, we found that within the group of selected patents technologies developed over the last years mostly focus on the **development of liquid fuels** (CPC Code: C10G 2/332, Cracking hydrocarbon oils; production of liquid hydrocarbon mixtures; Production of liquid hydrocarbon mixtures of undefined composition from oxides of carbon. 140 patents) and the **use of catalysts for the production of fuels** (e.g., B01J 23/75 – Chemical or physical processes; Catalysts comprising metals or metal oxides or hydroxides, not provided for in group; Cobalt. 110 patents; Y02P 20/52 – Climate change mitigation technologies in the production or processing of goods; Technologies relating to chemical industry; using catalysts. 92 patents; B01J 37/08 – Chemical or physical processes, e.g., Catalysis or colloid chemistry; their relevant apparatus; Processes for preparing catalysts; Processes for activation of catalysts. 89 patents; among other patents' classes). In addition, **oil refining systems using of bio-feedstock** (Y02P 30/20 – Climate change mitigation technologies in the production or processing of goods; Technologies relating to oil refining and petro chemical industry; using bio-feedstock. 82 patents) and **innovative processes for syngas production integrated with other chemical processes, like the FT processes** (C01B 2203/062-Non-metallic elements; compounds there of; Integrated processes for the production of hydrogen or synthesis gas; Integration with other chemical processes; Hydrocarbon production, e.g., Fischer-Tropsch process) represent other technological domains highly developed in the last years.

Key players in the biofuel innovation ecosystem

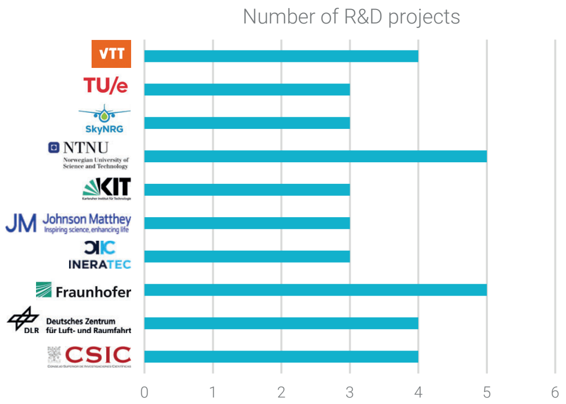


FIGURE 16 – TOP PARTICIPANTS IN THE SELECTED R&D PROJECTS

VTT Technical Research Centre of Finland Ltd, Fraunhofer-Gesellschaft in Germany, the Norwegian University of Science and Technology NTNU and the Spanish National Research Council CSIC are amongst the research organisations with most publicly funded R&D activities focused at technologies and materials for advanced biofuels production, especially for aviation and maritime sectors. **SkyNRG** from the Netherland, **Johnson Matthey** from UK and **INERATEC GmbH** in Germany figure as the most active industries in publicly funded R&D projects in this domain (Figure 16).

IFP Energies Nouvelles (France) and **ETH Zurich** (Switzerland) are the research organisations owning the highest number of patents identified in the sector (Patents in the sector in Figure 15) and patents with great affinity with glycerine valorisation processes (Selected patents in Figure 15). **SHELL International Research** (Netherland), **Siluria Technologies** (US) and **Virent** (US) are the top IP owners related to biofuels production. **Haldor Topsøe A/S** (Denmark) and **Nexceris** (US) are top IP owners focusing on the development of materials or catalysts for such processes. Among these companies, SHELL International Research, with more than € 200 bln of annual revenue, seems to be the company showing the highest investing potential and capacity.

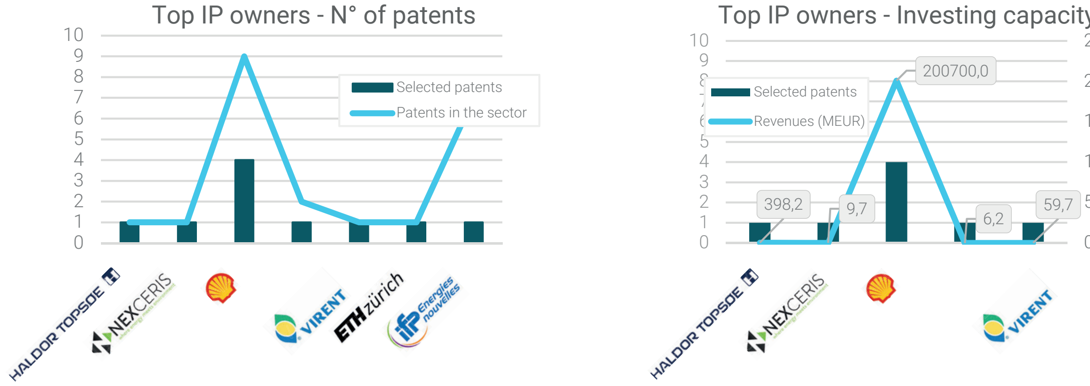


FIGURE 17 – TOP PATENT APPLICANTS IN THE SELECTED PATENTS

Relevant R&D network

Research organisations like CSIC, Fraunhofer, NTNU and VTT are core of the European innovation collaborative network on advanced biofuel development.

Figure 18 shows the collaboration network of a selection of the most active industries, RTOs and universities in the domain.

The figure helps spotting **some spiders in the web** within this R&D and innovation eco-system **showing most active stakeholders and connections**, e.g., research organisations such as **CSIC** (Spain) and **TU/e** (Netherlands), **Fraunhofer** (Germany), **NTNU** (Norway) and **VTT** (Finland). Each of these research organisations displays collaboration with at least one of the key industries operating in the biofuel field: e.g., **CSIC** collaborating with **INERATEC**, **GoodFuels**, **Vertoro** and **SkyNRG**, or **VTT** with **GoodFuels** and **Neste**, among others.

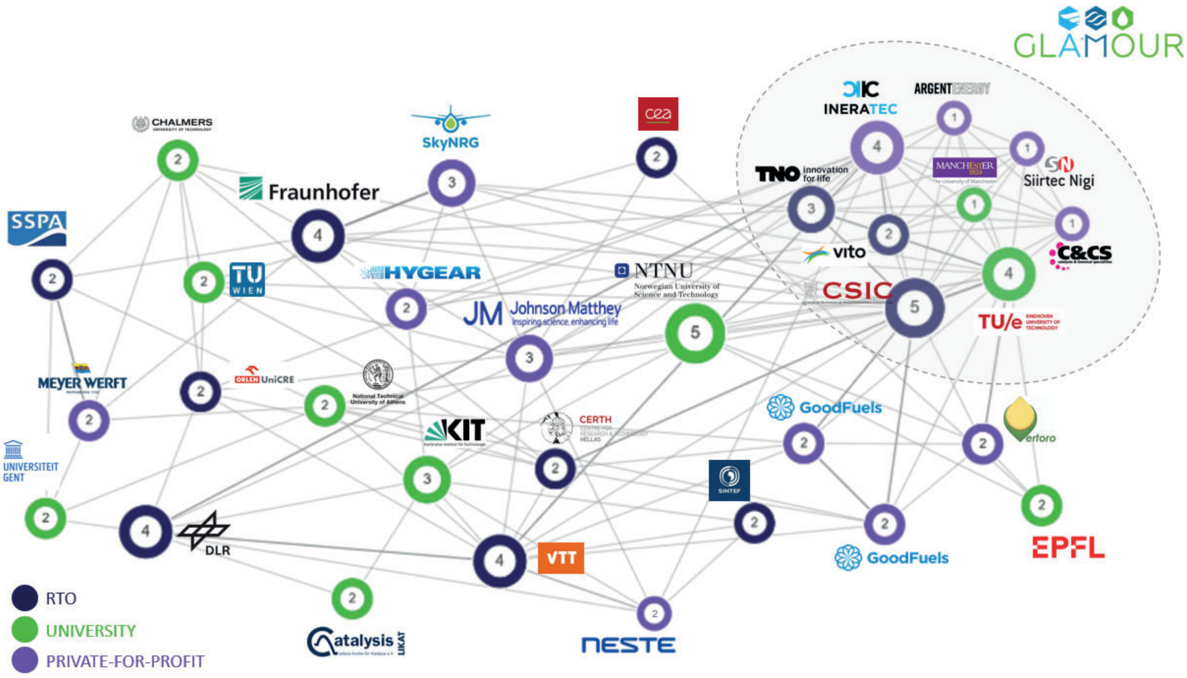


FIGURE 18 – NETWORK OF INNOVATORS (RTOS, UNIVERSITIES AND INDUSTRIES) FROM R&D PROJECTS ANALYSIS. THE NUMBERS INDICATE THE PROJECTS, THE LINES THE CONNECTIONS.

INERATEC, SkyNRG and GoodFuels figure as collaboration nodes in the R&D and innovation eco-system

Figure 19 maps all the private-for-profit organisations participating to relevant publicly supported R&D and innovation projects. The networking map shows industries with the highest number of R&D connections (with other companies). The German company **INERATEC**, and the three Dutch industries **SkyNRG**, **GoodFuels** (as well as the linked **SeaNRG B.V**) and **Vertoro**, are the private organisations operating in field of **innovative reactor technologies and next-generation fuels production** that have most established industrial collaborations for applied research activities in these projects. Another key player is **Johnson Matthey (UK)**, a global leader for **innovative catalysts development and production**. It is worth noticing that – aligned with the intense R&D activities – Johnson Matthey has also features relevant IP assets.

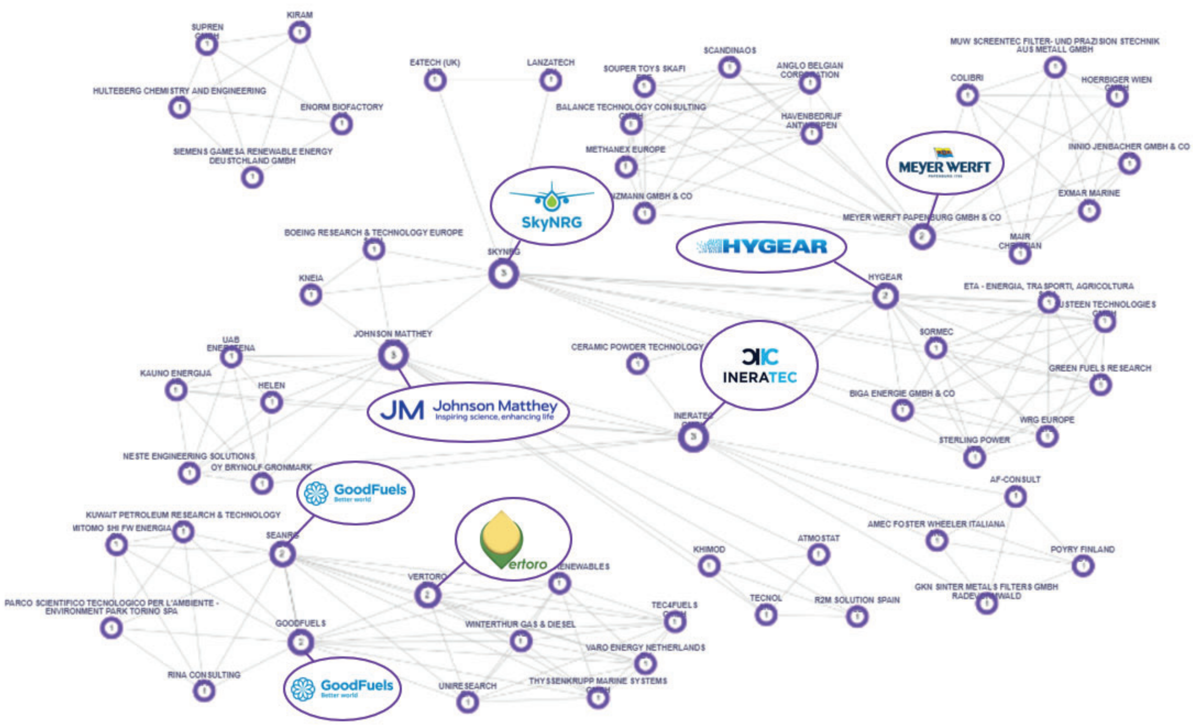


FIGURE 19 – R&D NETWORK MAP OF INDUSTRIAL INNOVATORS (GLAMOUR NOT INCLUDED IN THE FIGURE)

Value chain positioning and focus

By using the combined data obtained in this study, a simplified value chain is outlined. It is built based on the GLAMOUR supply-chain and the process developed in the project. It unfolds on 5 levels:

- **Feedstock:** this level includes the **feedstock providers**, such as crude glycerol providers (e.g., biodiesel producers).
- **Syngas generation:** this level includes: **materials producers**, i.e., producers of oxygen carriers, Ni-based catalysts and CaO-based sorbents needed for syngas generation; **process developers**, i.e., technology providers of chemical looping reforming process and producers of syngas through this process.
- **Fischer Tropsch process:** this includes **materials producers**, i.e., 3D printed catalysts for the FT reaction providers; **process developers:** Fischer-Tropsch reactor designers and users.
- **End-use:** this includes **fuel producers**, i.e., companies producing biofuels; **validators:** organisations with competences and expertise on validate the quality of the fuels produced.
- **Horizontal:** this includes the **experts and stakeholders** that are not specifically positioned along the production chain but that have a general interest on the process/product and have taken part in the innovation landscape, e.g., policy makers, sectorial associations and clusters, value chain assessment companies, exploitation services companies, etc.

Although it can only be indicative, and by no way it represents the exclusive focus or expertise of the indicated organisations, it quickly shows those players presiding different topics in the focus areas that have been observed in this study.

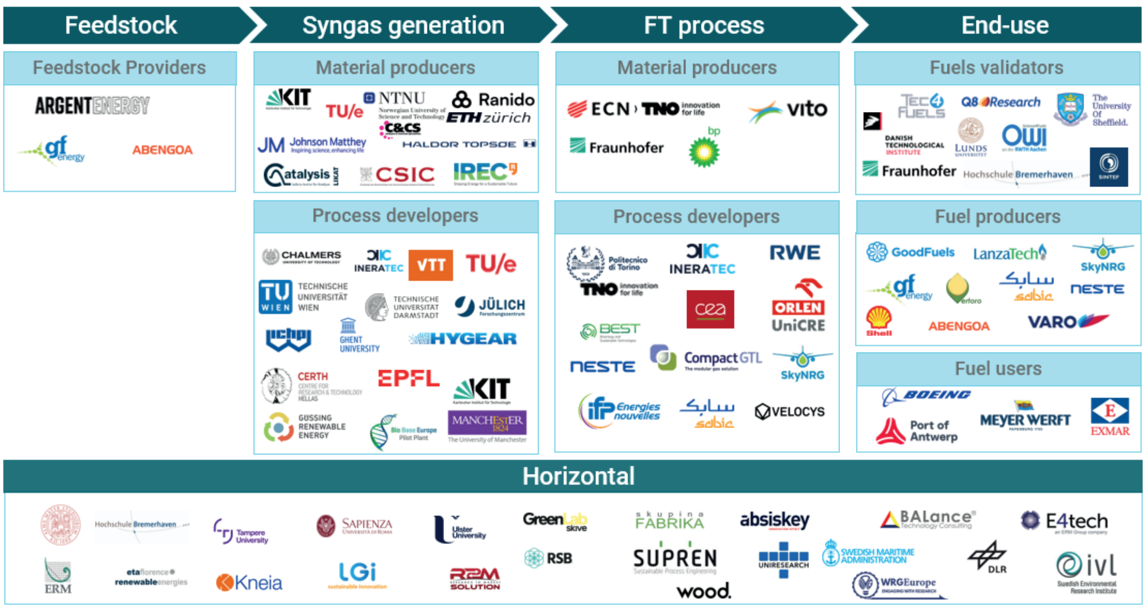


FIGURE 20 – KEY R&D PLAYERS VALUE-CHAIN POSITIONING FROM EUROPEAN R&D, INCLUDING PROJECTS AND PATENTS ANALYSIS

Market & innovation positioning map (MIPM©)

The Market and Innovation Positioning Map©[i] provides insight in:

1. The general landscape of the companies working on a particular technology topic.
2. Key – smaller/emerging - players with specific knowledge on the analysed subject matter
3. Large industries investing in a technology domain.

The analysis is based on an in-house qualitative and quantitative weighted measurement of stakeholders on a mixed scoreboard, positioning key stakeholders in a selected domain in 4 MIPM quadrants, defined by 2 axis:

- The X-axis takes into account both the R&D capacity in the field (including private and public funding and IP) and a specific *Affinity Index* which weights the proximity to the specific project technology at the centre of the analysis. In this specific case the *Affinity* was defined with respect to specific topics related to valorisation of glycerol as a side-stream towards biofuels.

- The Y-axis considers the capacity and structure to invest (e.g., turnover) compared to the nature of the organisation.

From the bottom to the top, the organisations with higher investing capacity or potential are positioned. Going from the left to the right instead, the organisations with higher specific domain knowledge and technologies are placed.

As a result, the upper-right quadrant defines organisations most likely to be market incumbents, whilst in the lower-right one relevant technology providers or visionaries can be found, with most specific knowledge with respect to the analysed topic.

- The upper quadrants identified **large leaders of the biofuel market (at EU and global level).** In this particular set-up the participation to publicly funded projects or ownership of relevant IP attribute a premium within the scoring system, leading to a high up right position of Research or IP intense stakeholders. This is the case of **Neste Oyj** (participating in publicly funded projects and having patents in the field) as well as Shell (displaying relevant IP assets as Shell Oil Company and Shell International Research). Specific catalysts developers and producers are also included, such as **Haldor Topsøe A/S** and **Johnson Matthey**, because of relevant IP.

[i] MIPM© is a PNO trademark based on is a proprietary methodology to map and graphically represent the position of organizations identified through a market and stakeholder analysis

- The lower quadrant highlights often **smaller but relevant and specialised players in the niche market analysed.** They all participated to relevant projects (with public and/or private funding) or do have relevant patents. Examples are, the German **INERATEC** and Dutch **Vertoro** have developed new FT technologies and biomass conversion systems for fuels production with market readiness, supported by both public and private funding.

The featured MIPM© map focuses exclusively on private for-profit companies. Important R&D stakeholders and experts don't show-up here, but are however visible in the Value-chain and R&D network presented in Figure 18 - Figure 20.

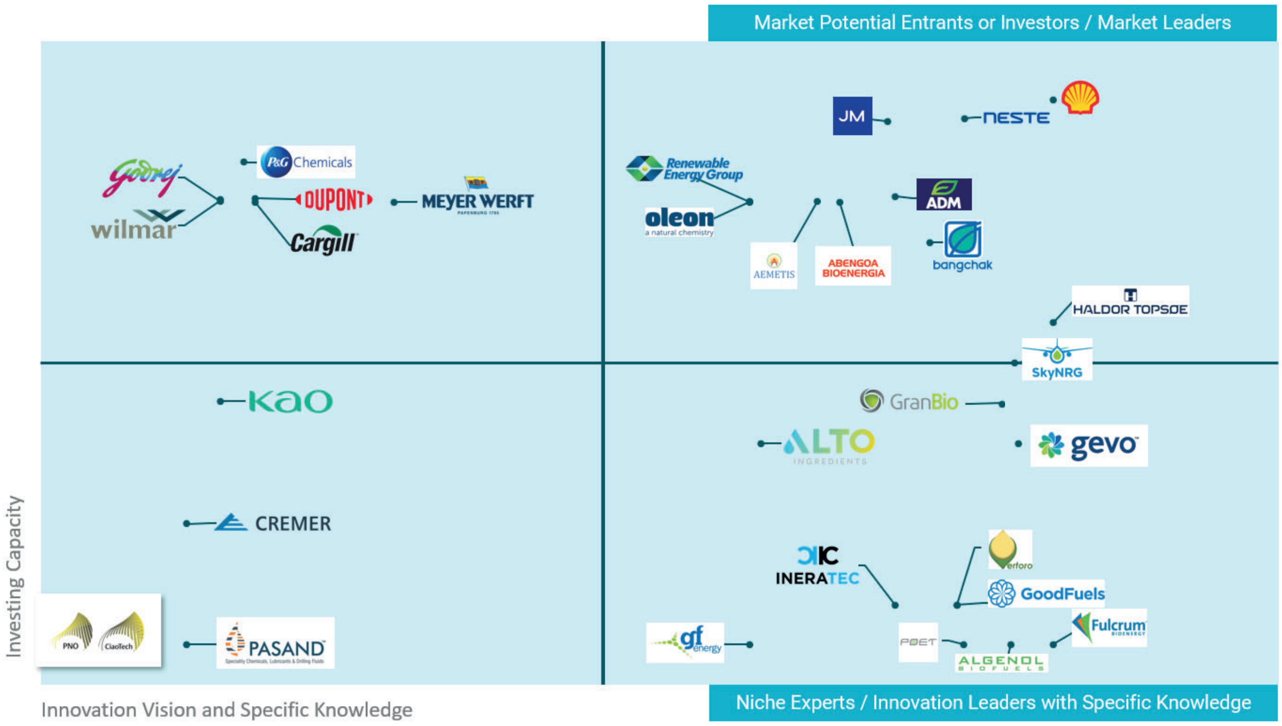
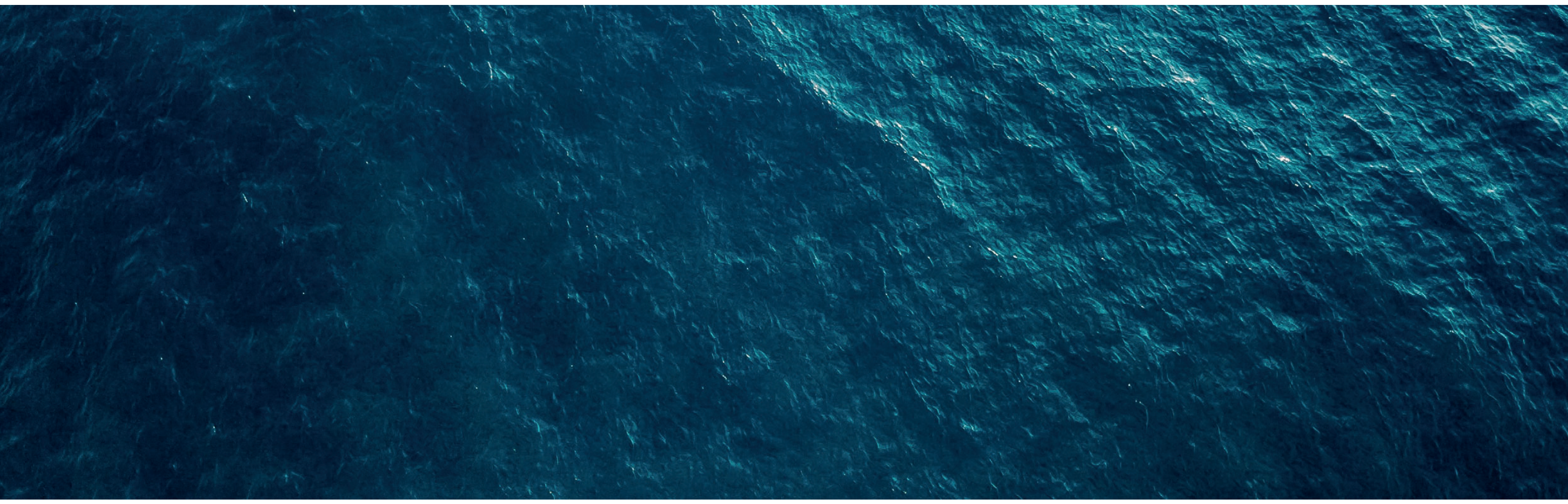


FIGURE 21 – MARKET & INNOVATION POSITIONING MAP©. THE MAP IS BUILT AROUND A SPECIFIC TOPIC RELATED TO DEVELOPMENT OF TECHNOLOGIES FOR ADVANCED BIOFUELS PRODUCTION, ALSO USING CATALYSTS.



CONCLUSIONS

This report dives in the global requirements for biofuels, and the related huge market potential for advanced biofuels, using crude glycerol – a by-product from biodiesel plants - as a scalable feedstock.

The technological development on this field is expected to effectively support the transition toward a decarbonised transport system, that nowadays represents a major priority for the EU.

Whereas the total biofuel market (which also includes the first-generation traditional biofuel) is predicted to grow with a CAGR of 7.8% over the upcoming 10 years, the **advanced biofuels segment**, which represents the most valuable option for a sustainable production of energy carriers, is expected to have an impressive annual growth potential of over **38% CAGR until 2025**. On the other hand, the analysis of the biofuel demand shows that to align with the IEA's Sustainable Development Scenario for reaching key SDGs and driving the decarbonisation of the transport sector, the output of biofuels needs to grow with 10% compared to the estimated total biofuels production growth. The **increased and potentially unmet demand for advanced biofuel in the coming years offers huge (environmental and business) potential for the EU** as leader in the global biodiesel market, a sector producing annually about 1.01 Mton of crude glycerol as by-product in Europe that can be potentially converted into advanced biofuels for aviation and maritime applications.

In order to establish a solid market for advanced biofuels, the development of innovative technologies that allow to overcome major barriers – e.g., the poor cost-competitiveness of products compared to fossil-based counterparts and the uncertainty on long-term supply of suitable feedstock - should be incremented. **More cost-efficient secondary biofuel production technologies are therefore needed** to convince investors to unlock sufficient financial resources.

In this context, key European and international organisations have been actively working on developing innovative and reliable and cost-effective technologies for advanced biofuel production. In the last six years, the R&D on this direction has attracted more than € 78 million of public funding and mobilised private investments, which are expected supporting industrial and research players overcoming main bottlenecks. Interestingly, unlike other technological domains, the R&D on advanced biofuels has seen a marked engagement of major European industries, such as **INERATEC**, **SkyNRG** and **GoodFuels**, which have established collaboration with leading research centres like **CSIC** and **TU/e**, **Fraunhofer**, **NTNU** and **VTT**. According to the innovation trends analysis, these organisations have recognised as key highly promising technologies the gasification and FT processing, among others. The analysis of the current market and main barriers shows that the deployment of a solid market for biofuels requires large investments and capabilities, which according to the MIPM© presented in this study might be expected to be vested in Shell, Neste Oil and **Johnson Matthey** as key players. In addition, some other smaller but specialised players however are likely to play a leading role to overcome the residual bottlenecks before advanced biofuels reach competitiveness and make inroads in the market (also due to regulation), as for example the German **INERATEC** and the Dutch **Vertoro**, among others.

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