

The availability of renewable feedstocks for the production of eligible fuels in Europe



Supporting the reduction of greenhouse gas emissions in the road transport sector



(selection of logos)

The [Working Group on Monitoring Methodologies \(WGMM\)](#), a voluntary platform that brings together stakeholders from across the entire automotive and fuel value chain, developed in its [2024 report](#) a technology-neutral definition of eligible fuels (formerly 'CO₂-neutral fuels'), which it recommends for a consistent application across all EU legislative acts.

The proposed definition is as follows:

'Eligible fuels' means all fuels defined by the Renewable Energy Directive (EU) 2018/2001, provided that they meet the sustainability criteria of that Directive and its associated delegated acts, where the same amount of CO₂ from biomass, ambient air or recycled carbon sources is bound in the fuel production as is released during combustion in the use phase. These fuels shall include renewable and/or synthetic fuels, such as biofuel, biogas, biomass fuel, renewable liquid and gaseous transport fuel of non-biological origin (RFNBO), or a recycled carbon fuel (RCF).'

The WGMM 2024 report further demonstrates that integrating eligible fuels into road transport would complement battery-electric and hydrogen-powered vehicles, and has the potential to accelerate the transition to climate neutrality.

This new report builds on the 2024 report, and assesses the availability in Europe of renewable feedstocks that can be used to produce eligible fuels, and examines how these resources can support the reduction of greenhouse gas emissions in the road transport sector over the medium and long term.

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Conversion of units

Tonnes (t) of oil equivalent, abbreviated as toe, is a normalized unit of energy. By convention it is equivalent to the approximate amount of energy that can be extracted from one tonne of crude oil. It is a standardized unit, assigned a net calorific value of 41.868 kilojoules/kg and may be used to compare the energy from different sources. Other energy carriers can be converted into tonnes of oil equivalent using the following conversion factors:

1 t diesel = 1.01 toe

1 m³ diesel = 0.98 toe

1 t petrol = 1.05 toe

1 m³ petrol = 0.86 toe

1 t biodiesel = 0.86 toe

1 m³ biodiesel = 0.78 toe

1 t bioethanol = 0.64 toe

1 m³ bioethanol = 0.51 toe

1 TWh = 0.086 Mtoe

Abbreviations

ATD	Alcohol-to-Distillates	IEA	International Energy Agency
ATJ	Alcohol-to-Jet	LDI	Liquid Direct Injection
Bio-CNG	Biogenic Compressed Natural Gas	LDV	Light-Duty Vehicle
Bio-LNG	Biogenic Liquefied Natural Gas	LNG	Liquefied Natural Gas
Bio-LPG	Biogenic Liquefied Petroleum Gas	LPI	Liquid Port Injection
BTL	Biomass-to-Liquids	LPG	Liquefied Petroleum Gas (including bio-LPG, e-LPG, rLPG)
CEN	European Committee for Standardization	MTD	Methanol-to-Diesel
CNG	Compressed Natural Gas	MTG	Methanol-to-Gasoline
CO ₂	Carbon Dioxide	Mtoe	Million Tonnes of Oil Equivalent
CO ₂ e	Carbon Dioxide Equivalent	OEM	Original Equipment Manufacturer
DME	Dimethyl Ether	PFAD	Palm Fatty Acid Distillate
EC	European Commission	PHEV	Plug-in Hybrid Electric Vehicle
e-Diesel	Electricity-derived Diesel	POME	Palm Oil Mill Effluent
e-LNG	Electricity-derived Liquefied Natural Gas (e-methane)	PtL	Power-to-Liquids
e-LPG	Electricity-derived Liquefied Petroleum Gas	PtX	Power-to-X (technologies that convert renewable electricity into various energy carriers or products; 'X' represents any one of a range of energy end products)
e-Naphtha	Electricity-derived Naphtha	RCF	Recycled Carbon Fuels
e-SAF	Electricity-derived Sustainable Aviation Fuel	RED	Renewable Energy Directive
ETG	Ethanol-to-Gasoline	RFNBO	Renewable Fuels of Non-Biological Origin
EU	European Union	rDME	Renewable Dimethyl Ether
EU-27	The 27 member countries of the European Union	rLG	Renewable Liquid Gas
FAME	Fatty Acid Methyl Esters	rLPG	Renewable Liquefied Petroleum Gas
FID	Final Investment Decision	SAF	Sustainable Aviation Fuel
FT	Fischer-Tropsch (synthesis/process)	SPGCI	S&P Global Commodity Insights
GHG	Greenhouse Gas	TWh	Terawatt Hour
GTL	Gas-to-Liquids	UCO	Used Cooking Oil
H ₂	Hydrogen	VPI	Vapour Port Injection
HDV	Heavy-Duty Vehicle	WGMM	Working Group on Monitoring Methodologies
HEFA	Hydroprocessed Esters and Fatty Acids	XTL	X-to-Liquids (conversion processes, e.g. GTL, BTL, CTL)
HEV	Hybrid Electric Vehicle		
HVO	Hydrotreated Vegetable Oil		
ICE	Internal Combustion Engine		

The background features a dark teal base with several overlapping circles in lighter shades of blue and teal. On the right side, there are multiple thin, parallel green lines that create a sense of depth and movement, resembling a stylized 'Z' or a series of chevrons.

Introduction

Introduction

This report assesses the availability in Europe of renewable feedstocks that can be used to produce eligible fuels, and examines how these resources can support the reduction of greenhouse gas (GHG) emissions in the road transport sector over the medium and long term.

The objective of the report is to provide policymakers and stakeholders with a clear, evidence-based overview of how renewable feedstocks can be mobilized to supply different types of eligible fuels for road transport, within the sustainability and GHG performance criteria of the European Union's (EU's) Renewable Energy Directive (RED).

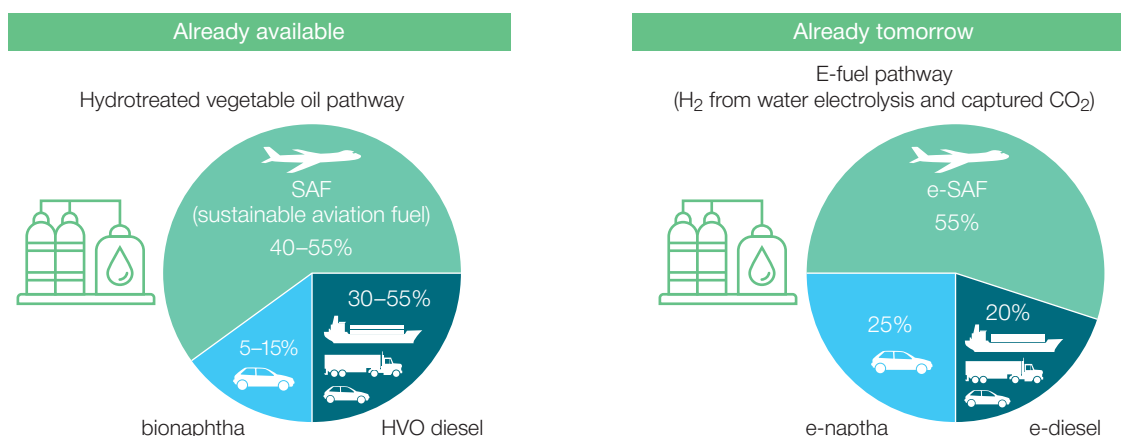
The analysis focuses on feedstocks and production pathways relevant to liquid and gaseous renewable fuels used in road transport, while accounting for competing non-energy uses and interactions across transport sectors. It draws on recent European and international studies to compare projected feedstock availability with potential fuel demand through 2030 and 2050.

The report was developed by the Working Group on Monitoring Methodologies (WGMM) and builds on its technology-neutral framework for the consistent and transparent assessment of renewable fuel pathways under EU legislation.

How renewable fuel production serves multiple transport sectors

The merit order principle¹ does not apply to renewable fuels as it does to electricity because the production of renewable fuels involves multiple synergies. Fuel production plants that use HEFA² and PtL/FT³ processes specifically to produce high-quality aviation (jet) fuel also co-produce road-suitable naphtha (15–25% of output), bio-LPG (10–15%) and diesel (20–25%) alongside SAF⁴ (60%)/e-SAF⁵ (55%) — see Figure 1. Using these co-products for road transport fuels (for both light- and heavy-duty vehicles) takes nothing away from the aviation sector but actually helps to reduce its impact on climate.

Figure 1: SAF and e-SAF plants always co-produce renewable road-suitable naphtha and diesel (values are illustrative)



¹ The 'merit order' system is a ranking system used to determine the order in which power plants provide electricity to the market based on their marginal costs, i.e. the cheapest sources are used first, and the more expensive sources brought online as demand increases. Electricity prices are dictated by the cost of the most expensive sources required to meet demand at a given time.

² Hydroprocessed esters and fatty acids

³ Power-to-liquids/Fischer-Tropsch

⁴ Sustainable aviation fuel

⁵ Synthetic aviation fuel derived from renewable energy

Valorizing SAF and e-SAF co-products in road transport helps to reduce the production costs of SAF and e-SAF, making these renewable fuels more economically competitive than fossil fuels, which in turn helps to reduce the climate impact of the aviation sector.

Renewable feedstock availability and biofuels demand up to 2050

Multiple studies^[1,2,3] have concluded that Europe possesses substantial potential for renewable biomass production for use in road transport even after competing uses have been accounted for. Agricultural and forestry residues represent the dominant contributors to biomass production, while biowastes play a supplementary role. Methodological assumptions regarding the mobilization of feedstocks, yield improvements and land use restrictions explain the variation between conservative and more ambitious estimates from these studies.

The study commissioned by Concawe and undertaken by Imperial College London Consultants (2021)^[3] estimated that the potential availability of advanced and waste-based biofuels⁶ could reach up to 79 million tonnes of oil equivalent (Mtoe) by 2030, and increase to 137 Mtoe by 2050. These figures were estimated after deducting the potential biomass availability required to meet the projected demand from non-transport sectors. The 2024 update of Annex IX^[4] under RED III⁷ (2023), which integrates intermediate crops and crops grown on severely degraded lands, increases the theoretical potential of feedstock availability for biofuel production. The publication of certification guidelines for these newly-integrated categories is eagerly awaited and, if these sources are to be utilized effectively, will need to ensure pragmatism and predictability while contributing

to the creation of new value chains that deliver benefits across all sectors involved. The availability of bioethanol is expected to be around 6.6 Mtoe in 2030 and 13 Mtoe in 2050. The availability of FAME⁸ made from conventional feedstocks is expected to be around 8.5 Mtoe in 2030 and 14.5 Mtoe in 2050. These assumptions are based on European production capacities and imports (via trade agreements).

When these feedstock potentials are compared with the demand for biofuels of 19–42 Mtoe (2030) and 35–94 Mtoe (2050) estimated in several studies,^[2,5,6] the analysis shows that Europe could satisfy the expected road transport renewable fuel requirements in 2030 and remain within feasible supply ranges in 2050. This suggests that, under the right enabling conditions, sufficient feedstock could be available to support both liquid and gaseous renewable fuel production over the long term.

The central challenge, therefore, is not the existence of feedstock, but the degree of mobilization and the cost-effectiveness of collection, transport and processing systems. Assessing and developing cost-effective supply chains for biofeedstocks will be essential to realizing this potential and meeting future biofuel demand.

The role of fuel retail infrastructure in scaling eligible fuels

Fuel retail infrastructure, particularly the extensive network of service stations across Europe, will play a critical enabling role in the large-scale deployment of eligible fuels. As the primary interface with end consumers, fuel retailers ensure immediate market access and user acceptance of new fuel products.

⁶ 'Advanced biofuels' utilize feedstocks derived from non-food waste and residues, as opposed to 'conventional biofuels' which utilize edible food crops.

⁷ RED III — the EU's [Renewable Energy Directive](#) as amended by [Directive \(EU\) 2023/2413](#) in 2023

⁸ Fatty acid methyl esters

Leveraging existing infrastructure allows for the rapid introduction of renewable and low-carbon fuels without the need for extensive new investments, thereby accelerating the energy transition in the transport sector.

In addition, service stations can play an important role in the circular economy, for example by acting as decentralized collection points for used cooking oils, which are among the feedstocks used for the production of biofuels.

Furthermore, independent and medium-sized operators contribute significantly to competition, security of supply and regional availability. Ensuring that regulatory frameworks support the integration of eligible fuels into existing retail systems is therefore essential to enable cost-effective, scalable and consumer-friendly market uptake.

Overall findings

The evidence indicates that Europe has sufficient renewable feedstock to underpin a robust portfolio of renewable fuels for road transport, provided that enabling conditions are in place. The main constraint is not the availability of feedstocks, but the ability to account for biofuels from a broader range of raw materials within mandatory targets and incentive schemes, as well as the extent to which collection, transport and processing systems can be mobilized cost-effectively. At the same time, the current fragmentation of feedstock requirements for the production of renewable fuels across different transport sectors continues to create uncertainty, and represents a major barrier to investment and market development. Moreover, diversity across fuel types reduces risk by spreading reliance across different feedstocks.

Co-product synergies such as the use of biogenic CO₂ for RFNBOs⁹ and bio-LPG from HVO¹⁰ also enhance system efficiency. Table 1 on page 5 summarizes the potential contribution of different biofuels to the reduction of GHG emissions in the EU road transport sector.

Conclusions

This 2026 WGMM report confirms that Europe's renewable feedstock base is broad and sufficient to support the scaling of renewable fuels in road transport through to 2050. FAME and HVO will support the reduction of GHG emissions from diesel fleets, while bioethanol and renewable gasoline molecules will contribute to reducing emissions from the petrol pool. Scaling lignocellulosic biomass and waste-based renewable fuels will be critical to unlock higher volumes of renewable fuels and deepen emissions reductions. RFNBOs represent a scalable electricity-linked option, renewable liquid gas provides flexibility for autogas users, and biomethane offers a highly effective solution for vehicles, especially for heavy-duty fleets. Together, these fuels can complement electrification, and there are clear opportunities to further increase their use to contribute to the energy transition and reduce the climate impact of the European road transport sector.

A diversified portfolio of feedstocks and fuel pathways strengthens the resilience and security of Europe's transport energy supply. By drawing on multiple domestic biomass feedstock streams, including agricultural, forestry and waste based resources, alongside RFNBOs and diversified imports, the road transport sector can reduce reliance on any single energy source or supply chain.

⁹ Renewable fuels of non-biological origin

¹⁰ Hydrotreated vegetable oil (renewable diesel)

Table 1: The potential contribution of different renewable fuels to reducing GHG emissions in the EU road transport sector

Feedstock type	Renewable fuel type	Current supply for transport (Mtoe)	Potential supply for transport in 2050 (Mtoe)	Demand for transport in 2050 (Mtoe) ^a
Crop-based feedstocks	Bioethanol, bio-maritime fuels, bio-SAF	4.6 ^b	12–14 (domestic) ^c	35–94
	HVO, FAME, bio-maritime fuels, bio-SAF	5.3 ^d	14.5 (domestic) ^d	
Annex IX B feedstocks	HVO, FAME, bio-SAF and bio-maritime fuels	3.3 ^d	9–33+ (domestic) ^e	
Annex IX A feedstocks	Bio-based renewable diesel (HVO, FAME, lignocellulosic biomass and waste-based), bio-based renewable gasoline/ bioethanol, bio-SAF and bio-maritime fuels	4.2	32–137 (domestic) ^f	
Allowable H ₂ and CO ₂ sources	RFNBOs	0	151 (global) ^g	39–64
Gases from renewable feedstocks	Renewable liquid gas (e-LPG, e-DME)	0.2	3.8 (domestic)	6–12 ^j
	Renewable methane (biomethane)	0.5 ^h	16–32 (domestic) ⁱ	
TOTAL RENEWABLE FUELS		18.2	238.8–386	80–170 ^k

Notes:

- ^a Based on two potential demand scenarios: 'Scenario 3' for 2050 in the EU's impact assessment on 'Europe's 2040 climate target and path to climate neutrality by 2050',^[7] which foresees that renewable fuels will be utilized firstly in the maritime and aviation sectors with a supporting role in road transport, and the 'More Molecule Scenario' from the S&P Global study (2025)^[5] which demonstrates a higher ambition for renewable fuels by relaxing the requirements of the LDV and HDV vehicle standards and allowing sales of some new internal combustion engine cars and vans after 2035, and postponing any electrification in the aviation and marine sectors until after 2050.
- ^b Source: ePURE, 2024a^[8]
- ^c Source: ePURE (based on estimates of capacities and ethanol quotas via free trade agreements)
- ^d Source: Modelled supply based on data from Eurostat's SHARES^[9] database and the EBB *Statistical Report 2024–2025*^[10]
- ^e For the Annex IX Part B feedstocks for FAME and HVO, we indicate a figure of 33 Mtoe+ for the potential supply for transport, but intermediate crops can count in both Annex IX Parts A and B. The potential for intermediate crops (indicated by the '+') is based on a European Commission study undertaken in 2024^[11]
- ^f Source: Imperial College London Consultants/Concawe, 2021^[3]
- ^g Estimated availability for the EU from global e-fuel/RFNBO availability. Source: eFuel Alliance and Porsche Consulting, 2026^[12]
- ^h Source: SHARES^[9]
- ⁱ Potential production in 2050 = 165 bcm (billion cubic metres) = 142 Mtoe, of which the share attributed to transport is 23% (current share of biomethane for transport). Source: Gas For Climate study, 2022^[13]
- ^j The demand for renewable methane for transport in 2050 is derived from the Eurogas 2050 scenario (internal calculation, 2025), assuming that 10% of the HDV fleet would be powered by renewable methane.
- ^k Projection (real balance will be defined by markets, production, etc.)



Availability of feedstock

Availability of feedstock

Renewable biofuels are expected to play a crucial role in supporting the energy transition in the EU transport sector. With the anticipated strong growth in demand for low-carbon fuels in transport, a key question arises: is there sufficient renewable biomass available in Europe? It is also necessary to note that the Renewable Energy Directive (2018/2001)^[14] provides the sustainability and GHG emission savings criteria which renewable fuels must fulfil to be eligible for being counted towards the climate and energy targets in the EU.

Several studies have been conducted over the past decade that aimed to address the question of biomass availability and map biomass density across Europe. Four recent studies that provide insights into these questions are highlighted below:

- *The JRC-EU-TIMES model: Bioenergy potentials for EU and neighbouring countries* by the Joint Research Centre of the European Commission, 2015.^[15]
- *The 'DG RTD study': Research and innovation perspective of the mid-and long-term potential for advanced biofuels in Europe* by the European Commission's Directorate for Research and Innovation (DG RTD), 2017.^[1]
- *The Imperial College/Concawe study: Sustainable biomass availability in the EU, to 2050* by Imperial College London Consultants, commissioned by Concawe, 2021.^[3]
- *The 'DI Fuels' study (Task 2 of the study): Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels* by the European Commission, 2024.^[11]

All four studies seek to assess domestic biomass availability for bioenergy uses, with each presenting three future scenarios:

- **low scenario** (most conservative, e.g. business as usual);
- **medium scenario** (e.g. biomass production improvement in certain EU countries); and
- **high scenario** (e.g. extended level of biomass production improvements across Europe).

However, each study is based on different assumptions and approaches when modelling these scenarios. The DI Fuels study (2024),^[11] which is the most recent study, is the only one to incorporate the new biofeedstocks included in the revised Annex IX of the RED, while the others rely on the previous version of Annex IX. Notably, all studies adopt a harmonized geographical approach, focusing on the EU-27 + UK to ensure consistent availability potential and trends. To provide reliable estimates of biomass for bioenergy, projected demand for biomass in both traditional and emerging material applications (e.g. bioplastics, biochemicals) was subtracted from total availability.

Figure 2 on page 8 presents the biomass availability potential for bioenergy as estimated in each study for both transport and non-transport energy demand for 2030 and 2050. All the studies find that agricultural and forestry biomass serve as the primary drivers for the total biomass potential. However, there are variations among the studies regarding whether agricultural or forestry biomass is deemed more significant. Conversely, biowastes consistently make a marginal contribution to the total availability.

Figure 2: Biomass availability (feedstocks listed in RED Annex IX, Part A) for bioenergy estimates for the low, medium and high scenarios as calculated in the JRC-EU-TIMES, 'DG RTD', Imperial College/Concawe and 'DI Fuels' studies for 2030 and 2050



Note: Wastes in this figure refer to biowastes (paper cardboard, wood waste, animal and mixed food waste, vegetal waste, and municipal solid waste).

The DI Fuels study estimates the lowest biomass availability potential, especially in its low scenario, despite being the only study to incorporate the newly added biofeedstocks from the revised Annex IX (a broader range of biofeedstocks was analysed). Indeed, the DI Fuels study applies very conservative assumptions about biomass use for bioenergy and competition from other sectors, which contribute to these lower availability figures. For example, the study assumes that only 10% of marginal land will be used for energy crop production by 2050—a notably lower figure compared to the Imperial College/Concawe study (2021),^[3] which assumes 25% of marginal land utilization in its low scenario, and that only 5 to 10% of the available land would be used for intermediate and cover crops. This conservative approach is acknowledged and highlighted within the DI Fuels report.^[11]

The JRC-EU-TIMES study (2015)^[15] takes a more inclusive approach, as it considers advanced biofuels, as well as conventional biofuels which currently account for more than 90% of biofuel production.

The JRC-EU-TIMES medium scenario, which is based on bioenergy development following the current trend and meeting all sustainability criteria, shows that the maximum biomass potential comes from agricultural biomass.

The majority of agricultural biomass is first-generation biomass.¹¹ The Nova Institute produced a study paper on this topic in September 2025, entitled *Benefits of Using First-Generation Biomass for Food, Fuels, Chemicals and Derived Materials in Europe*.^[16]

¹¹ First-generation biomass refers to organic matter and crops grown primarily for human consumption (e.g. corn, wheat, food grains and sugarcane).

The new research highlights four key benefits to the EU from the use of biomass, including agricultural crops, for non-food applications such as fuels, chemicals and materials:

- **Enhancing a resilient and competitive EU agriculture:** Selling crops to multiple markets allows farmers to diversify their income and have greater flexibility and less vulnerability to price fluctuations in single sectors, while encouraging investment in innovation and practices that reduce the impact on climate.
- **Increased food security:** Using first-generation biomass for non-food applications strengthens food security in several important ways. This includes improved market stability through delivering protein-rich by-products, providing good availability of food crops and long-term scalability for starch, sugar and oil crops in the EU, all while providing an emergency food reserve in times of crisis.
- **Supporting climate change mitigation:** In order to reduce reliance of fossil fuels/feedstocks in European industry, the use of first-generation biomass is indispensable. Although the use of second-generation biomass is widely accepted, first-generation biomass can usually be produced at lower cost and scaled up more easily and more significantly.
- **Supporting biodiversity protection:** Agricultural crops are the most efficient use of land for producing starch, sugar and plant oils; maximizing the productivity of each hectare reduces the total land area required for agriculture, leaving more space for nature and biodiversity protection.

For the other main driver, forestry biomass, the JRC-EU-TIMES study followed an optimistic approach in its high scenario assuming a reduction in biomass demand for non-energy purposes, increased productivity in woodland, and greater mobilization of wood from small private forest owners. On the other hand, the DI Fuels,^[11] DG RTD^[11] and Imperial College/Concawe^[3] studies used a more conservative approach. For instance, the DG RTD study assumed a rise in wood demand from the bio-based industry, while the Imperial College/Concawe study assumed that the majority of wood material will be directed towards materials production, accounting for 50–80% of the total wood production rate.

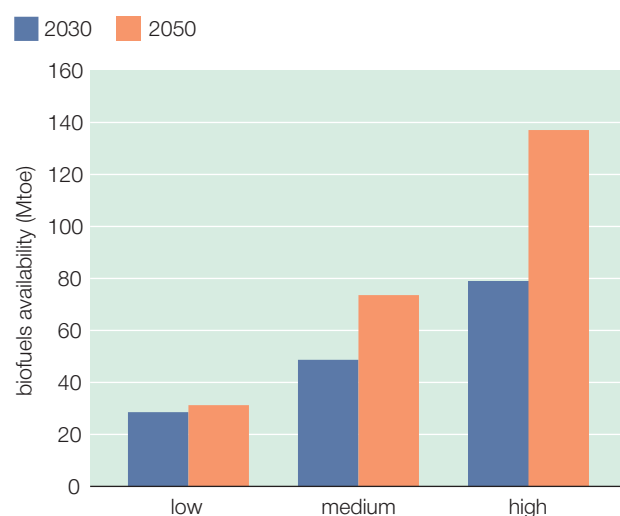
Therefore, when disregarding the high availability scenarios of each study, which may include optimized methodological choices, it can be noted that these studies converge on similar estimates for biomass availability potential.

The Imperial College/Concawe study also calculated the availability potential for biofuels from lignocellulosic and other feedstocks listed in Annex IX after deducting the projected biomass demand in non-transport energy uses from the total biomass availability for bioenergy presented above, using representative biomass-to-biofuel conversion yields (Figure 2). For the projected non-transport energy demand, the biomass results from the PRIMES model published in the European Commission's Impact Assessment on Europe's 2030 climate ambition (2020)^[17] were subtracted (130 Mtoe in 2030, 170 Mtoe in 2050). The remaining domestic biomass potentially available for transport results in an availability potential for advanced biofuels of 29–79 Mtoe (2030) and 32–137 Mtoe (2050), depending on the scenario (low–high). Currently the incorporation of biofuels in Europe coming from advanced feedstocks is around 4 Mtoe (Eurostat data for 2020¹²).

¹² <https://ec.europa.eu/eurostat/en/>

The differences in results between the scenarios in the Imperial College/Concawe study reflect varying degrees of technological and management improvements in agriculture and forestry, and assumptions regarding the mobilization of biomass resources. The low availability scenario assumes that farming and forestry practices remain at 2020 levels. The medium scenario considers improved mobilization in countries with high biomass availability, while the high scenario assumes further advancements through research and innovation and improved mobilization across all EU member states. An analysis of the scenarios from 2030 to 2050 shows a consistent increase in biofuel potential. This rise is primarily due to the greater biomass availability projected for 2050 compared with 2030, as well as improvements in biofuel processing yields resulting from technological advancements. The findings underscore the sector's significant potential, which can only be realized through sustained political commitment and enabling policy measures to unlock this potential. Figure 3 summarizes these conclusions.

Figure 3: Domestic biofuels availability potential for low, medium and high scenarios for 2030 and 2050 according to the Imperial College/Concawe Study, 2021^[3]



Furthermore, the potentials shown in the Imperial College/Concawe report (2021)^[3] could increase due to the revision of Annex IX of the RED, allowing intermediate crops and crops on severely degraded land to be considered as Annex IX Part A feedstocks if used to produce sustainable aviation fuel, and as Annex IX Part B feedstocks for use in other transport sectors.

Comparison of potential biomass availability with biofuels demand

To assess the sufficiency of renewable biomass resources, the availability potential for biofuels was compared with estimates of potential biofuels demand in Europe given in recent studies, namely the aforementioned DI Fuels study, the S&P Global Commodity Insights (SPGCI) study (2025)^[5] commissioned by Concawe, and the EU's 2040 climate target Impact Assessment (2024).^[7]

The DI Fuels study estimated biofuels demand inclusive of legislative updates, including RED III^[18] and the Fit for 55 package^[19] using the PRIMES model:

- For 2030, several scenarios were assessed, assuming limited deployment of electric vehicle technologies by 2030, for differing levels of GHG reduction. In the Fit for 55 RED scenario, which achieves a 14.5% GHG reduction and 30% renewable energy sources in transport, the estimated total biofuels demand was 38.1 Mtoe, comprising food and feed crop-based biofuels (10.6 Mtoe), Annex IX Part A biofuels (18.4 Mtoe), and Annex IX Part B biofuels (9.1 Mtoe).
- For 2050, the estimated total biofuels demand was 46 Mtoe, comprising Annex IX Part A biofuels amounting to 40 Mtoe with the remainder being Annex IX Part B biofuels.

The EU's 2040 climate target Impact Assessment evaluated the implications of alternative net GHG emission reduction targets for 2040. The assessment foresees a biofuels demand of approximately 19 Mtoe in 2030, taking into account the electrification of road transport. Scenario 3 (S3), which achieves a 90–94% reduction relative to 1990 levels, foresees a biofuels demand of approximately 47 Mtoe in 2040, declining to around 35 Mtoe by 2050.

The SPGCI study evaluated the impact on the refining and fuel manufacturing industrial assets of two hypothetical scenarios which both meet the net zero GHG emission objective by 2050 in the EU-27 plus Norway, Switzerland and the UK. Both scenarios share a common basis for the transition of most economic sectors but differ on the GHG emissions reduction pathway for the transport sector.

The first scenario in the SPGCI study—the 'Max Electron' scenario—meets all requirements of the Fit for 55 package while surpassing the requirements of the EU's regulation on CO₂ standards for heavy-duty vehicles¹³ by assuming zero sales of internal combustion engine (ICE) vehicles after 2035, and assumes an accelerated and unprecedented rate of electrification across various modes of transportation. The second scenario—the 'More Molecule' scenario—was derived from the Max Electron scenario by relaxing the requirements of the light-duty vehicle (LDV) and heavy-duty vehicle (HDV) standards and allowing sales of some new ICE cars and vans after 2035, as well as postponing any electrification in the aviation and maritime sectors until after 2050. In this way, this scenario achieves net zero in 2050 by complementing electrification with an increased use of low-carbon fuels.

The SPGCI study estimated the demand for biofuels in the Max Electron and More Molecule scenarios as follows:

- **Max Electron scenario:** For 2030, the total biofuels demand ranged from 35.5 to 42.2 Mtoe, comprising food and feed crop-based biofuels (19.8–20.3 Mtoe), Annex IX Part A biofuels (8.2–14.2 Mtoe) and Annex IX Part B biofuels (7.5–7.7 Mtoe).
- **More Molecule scenario:** For 2050, the total biofuels demand ranged from 62.1 to 93.9 Mtoe comprising Annex IX Part A biofuels (56.9–88.2 Mtoe) and Annex IX Part B biofuels (5.2–5.7 Mtoe).

It is observed that, in 2030, the demand for biofuels estimated by these studies differs depending on assumptions made about the share of electricity in the final energy demand. For 2050, the SPGCI study foresees a significantly higher total biofuels demand in both of its scenarios compared to the DI Fuels study or the EU's 2040 climate target Impact Assessment. This is attributed to the larger geographical scope of the SPGCI study, as well as differing assumptions on activity growth in the different sectors. Further, the More Molecule scenario assumes that sales of new ICE LDVs and HDVs are allowed beyond 2035, and postpones electrification in the aviation and maritime sectors until after 2050.

¹³ https://ec.europa.eu/commission/presscorner/detail/en/qanda_24_2527

Figure 4 compares the biofuel demand projected in the aforementioned studies with the potential domestic biofuel availability in 2030 and 2050, as reported by the Imperial College/Concawe study and shown in Figure 3 on page 10. In 2030, the total estimated demand falls within the projected range of domestic availability. By 2050, the estimated demand in the SPGCI Max Electron scenario, the DI Fuels study and the EU's 2040 climate target Impact Assessment scenarios lies in the lower to mid-range, while in the SPGCI More Molecule scenario demand approaches the upper limits. This implies that improved collection practices from agriculture and forestry will be required to achieve the higher mobilization of biomass and reduce the need for imports, particularly in the More Molecule scenario where there is a greater requirement for advanced feedstocks.

While the DI Fuels and DG RTD biomass availability studies did not offer specific figures for translating biomass availability into biofuels potential, similar conclusions can be drawn from the DG RTD study due to the small differences in domestic biomass availability results. The only instance of potential insufficiency between resources and demand occurs in the low scenario of the DI Fuels study, but this scenario is based on a very conservative approach to calculating biomass availability.

It should be noted that the potential availability of renewable biomass presented in the studies does not entail that all of it will be economically viable for mobilization. Therefore, assessing and developing cost-effective supply chains for solid biofeedstocks will be essential to realize this potential and meet future biofuel demand.

Finally, according to the International Energy Agency (IEA) report, *Delivering Sustainable Fuels, Pathways to 2035*,^[20] published in October 2025, the supply in terms of renewable fuel in the next 10 years will be enough to cover the demands from the different sectors.

Figure 4: Comparison of biofuels demand for all sectors (Max Electron and More Molecule scenarios) reported in the SPGCI study (2025)^[5] with the biofuels availability potential as reported in the Imperial College/Concawe study (2021)^[3]

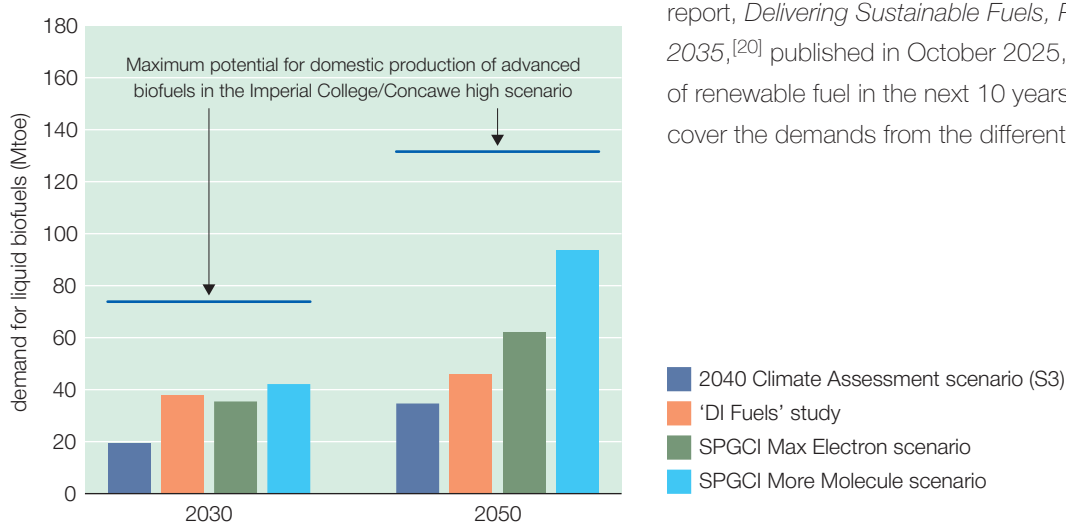
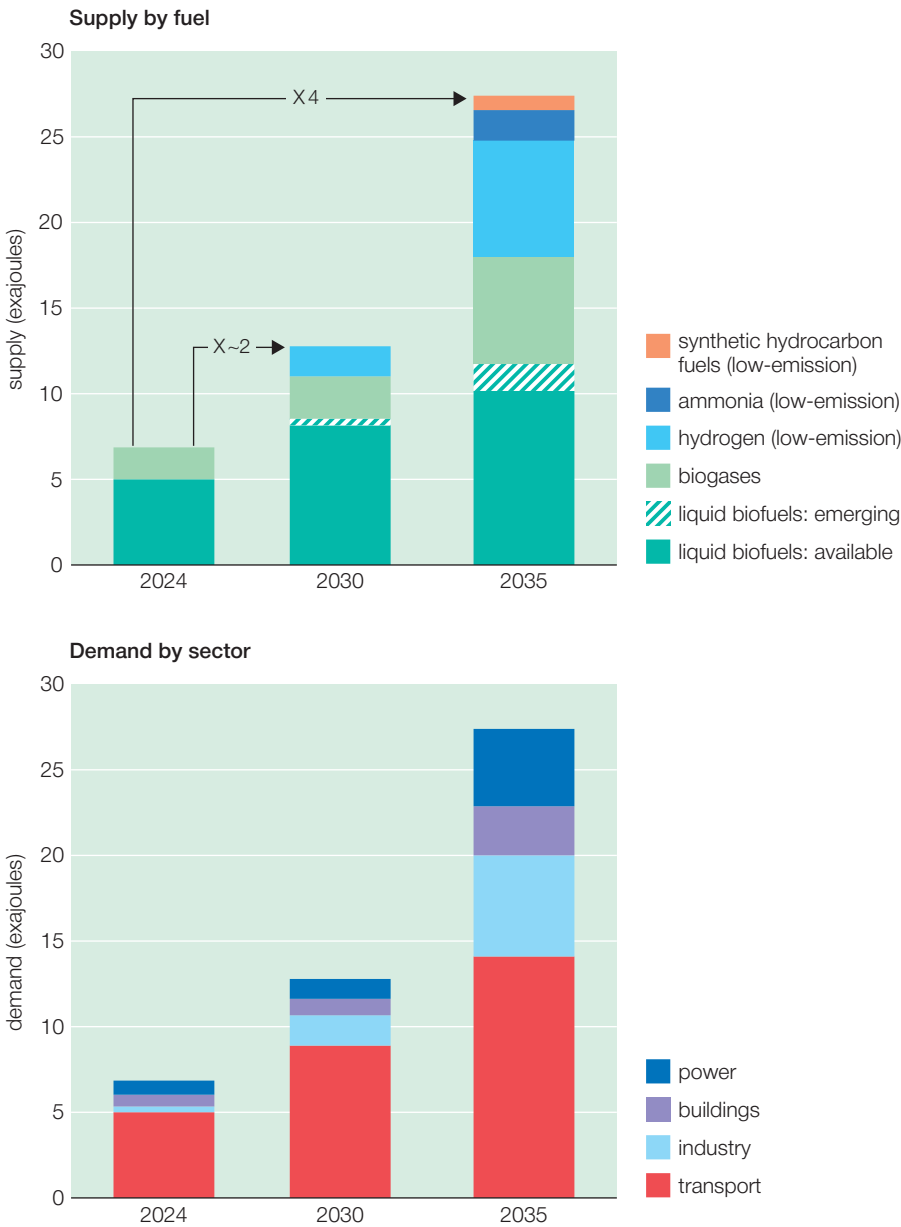


Figure 5: Renewable fuel supply by fuel, and demand by sector, in the accelerated case, 2024–2035
(Source: IEA, 2025)^[20]



Fuels

Fuels

Renewable fuels for diesel engines

Overview

Biofuels for diesel engines, such as biodiesel (FAME) and renewable diesel (HVO), are well-established and contribute significantly to the EU's objectives to reduce GHG emissions in the transport sector. They can be used in current infrastructure without the need for modifications.

Biodiesel and renewable diesel in the European Union are produced from a variety of feedstocks, including those listed in Part A and Part B of Annex IX of the EU's RED, that fulfil the sustainability and GHG emissions savings criteria of the RED.

The use of biodiesel and renewable diesel in transport is already established across EU member states, with both standard and higher blends in circulation (HVO is already commercially available in 100% neat form). The presence of captive fleet programmes using blends above B10¹⁴—such as B20, B30 and B100—demonstrates operational experience and flexibility in controlled fleet settings.

Biodiesel (FAME)

In the EU, biodiesel encompasses mainly FAME, produced through the transesterification of oils or fats. It can be used in pure form or blended with conventional diesel. According to the EBB *Statistical Report 2024–2025*,^[10] EU production of FAME reached approximately 10 million tonnes in 2024, reflecting a stable and mature sector that continues to support renewable energy targets under RED III.

FAME can be produced from a wide range of feedstocks, eligible under the RED. Rapeseed is the main feedstock but feedstocks under Annex IX of RED are growing their share.

FAME is currently limited to a maximum blending ratio of 10% (B10) in diesel fuel with the introduction of a protective grade with a blending ratio of 7% (B7), as defined by the European Commission's Fuel Quality Directive^[21] (FQD) in Article 4 and Annex II. However, this threshold does not fully reflect the technical and environmental potential of FAME as a renewable alternative to fossil diesel. Several countries have already introduced B10+ blends to consumers, demonstrating that it is possible to meet all requirements of the CEN¹⁵ European fuel standard EN 590¹⁶—except for the FAME content—while maintaining fuel quality and engine compatibility. This suggests that the current blending limit could be reconsidered, provided that fuel stability, performance and compliance are ensured.

Renewable diesel (HVO)

Renewable diesel is a paraffinic diesel produced by hydrotreating fatty acids and lipid feedstocks, for example used cooking oil (UCO) and other waste and advanced feedstocks (See Table A2, *Estimated feedstock availability, collection rate, key constraints and opportunities*, in the Appendix). According to the EBB *Statistical Report 2024–2025*,^[10] EU production of HVO reached nearly 4 million tonnes in 2024.

¹⁴ Bxx = diesel fuel blend containing xx% biodiesel

¹⁵ European Committee for Standardization

¹⁶ European Standard EN 590: *Automotive fuels - Diesel - Requirements and test methods*

Its production process co-produces bio-LPG, bionaphtha and biojet (SAF). Its GHG reduction potential depends on the feedstock and the process energy but is generally substantial (up to 90% on a life-cycle basis) when waste and residue-based feedstocks are used. HVO production has been expanding steadily, and it is provided as a blend and as pure/unblended HVO on the market. In the short term it has the potential to reduce GHG emissions from light-duty vehicles (LDVs) and, in particular, from heavy-duty vehicles (HDVs) and some maritime applications, in synergy with HEFA-SAF for aviation.

HVO is composed of a mixture of stable, non-hygroscopic paraffins, showing excellent storage stability due to its chemical structure, which prevents oxidation, water absorption, microbial growth and thus bacterial contamination. Thanks to its nature, it is already available on the market either in pure form (i.e. 100% HVO) or blended with fossil diesel fuel in high percentages (for use as a drop-in fuel).

Being practically free of aromatics and sulphur, HVO is a clean-burning paraffinic diesel fuel that complies with the requirements of CEN standard EN 15940¹⁷ for paraffinic diesel fuel produced via synthesis or hydrotreatment (known as XTL¹⁸ diesel fuel).

For details of the range of properties required by the EN 15940 specification, see Table A1 in the Appendix.

GHG savings and availability of feedstocks for FAME and HVO

Biodiesel and renewable diesel deliver significant life-cycle GHG emissions savings compared to fossil diesel across a wide range of feedstocks. Under the RED II¹⁴ methodology, life-cycle emissions are assessed across the full fuel production chain—from feedstock sourcing to final combustion—allowing for a standardized comparison. The emissions from the combustion of a biofuel are to be taken as zero in the RED GHG methodology.

In alignment with that, the ETS Implementing Regulation (EU) 2018/2066,¹⁹ providing the rules for monitoring and reporting GHG emissions in the EU, states that the emissions from the combustion of a biofuel are 'zero-rated' and that a biofuel is a 'zero-rated fuel', when it complies with the RED sustainability and GHG emissions savings criteria.

¹⁷ European Standard EN 15940: Automotive fuels – Paraffinic diesel fuel from synthesis or hydrotreatment - Requirements and test methods

¹⁸ XTL stands for 'X-to-Liquid' where the 'X' refers to various raw materials, e.g. biomass (BTL), biogas (GTL), and CO₂, water and electricity (PTL—Power-to-Liquid) that are converted into high-quality synthetic e-fuels.

¹⁹ EU Regulation on the monitoring and reporting of greenhouse gas emissions for the EU Emissions Trading System (ETS)
https://eur-lex.europa.eu/eli/reg_impl/2018/2066/oj/eng

Table 2: Typical and default GHG emissions savings according to RED Annex V, Part A (revised (EU) 2018/2001)

Feedstock and fuel	GHG emissions savings according to RED II Annex V, Part A (revised, EU 2018/2001) (typical/default)
RED fossil fuel comparator is 94 gCO ₂ e/MJ ^[14]	
Biodiesel from waste cooking oil	88% / 84%
Biodiesel from rendered animal fats	84% / 78%
Hydrotreated oil from waste cooking oil	87% / 83%
Hydrotreated oil from rendered animal fats	83% / 77%

Notes: GHG emissions savings are calculated over the fuel's full life cycle using the EU RED III methodology, compared to the fossil fuel comparator of 94 gCO₂e/MJ. Actual GHG emissions savings can be higher than the values shown.

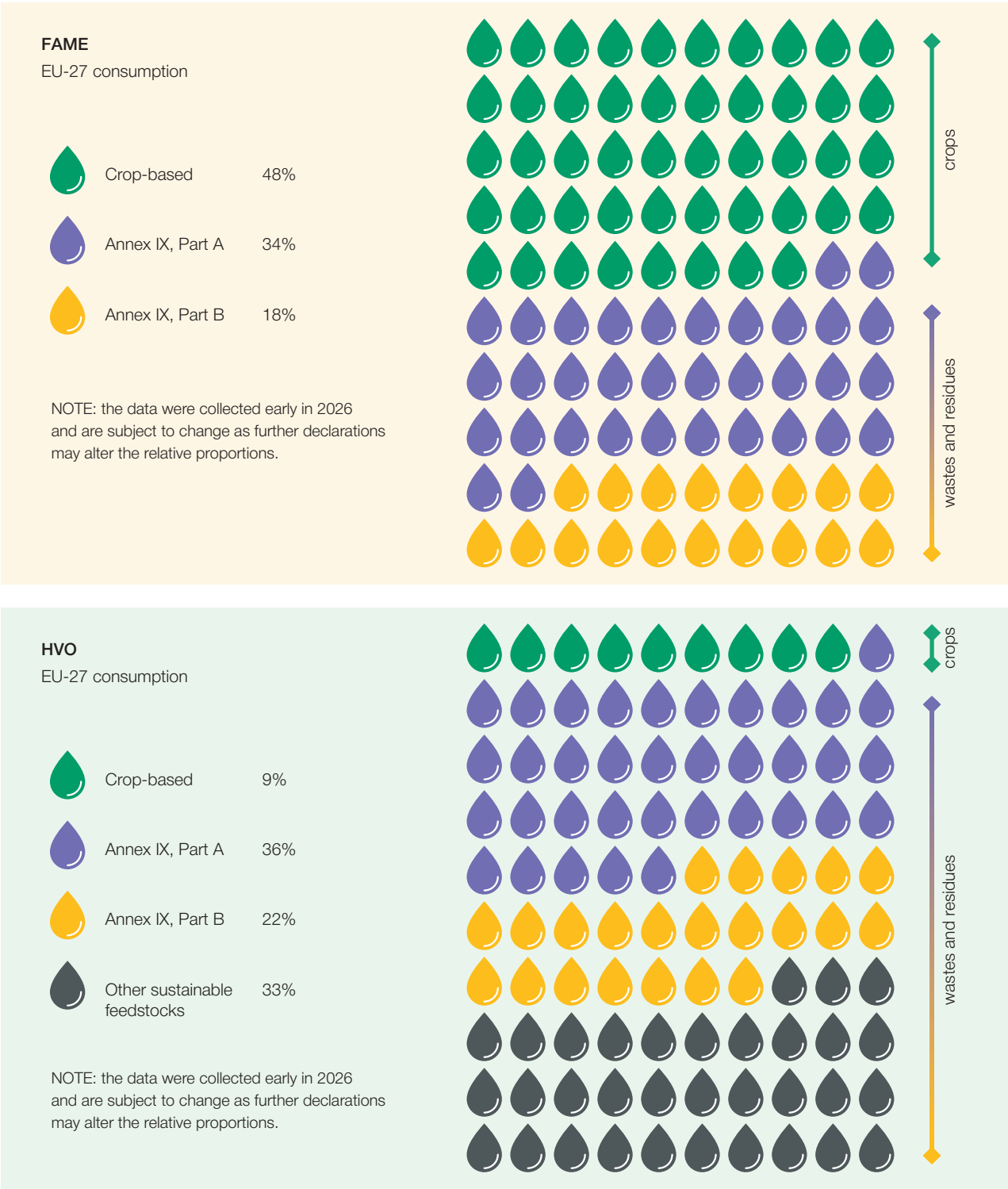
According to the RED II, Annex V, the typical and default GHG emissions savings for FAME and HVO made from UCO or animal fats range between 77%–88% (see Table 2). Actual GHG emissions savings can be higher than the defaults. The EEA/ETC-CM report, *Greenhouse gas intensities of transport fuels in the EU in 2022. Monitoring under the Fuel Quality Directive*,^[22] reports that in 2022, the average GHG intensity of HVO was 10.1 gCO₂e/MJ, meaning that HVO used in the EU in 2022 provided on average 89% GHG emissions savings compared to fossil fuel. Current production has delivered further improvements, with GHG emissions savings of up to 90% compared with fossil diesel (calculated in accordance with the EU RED III methodology) when biofuels are produced from waste and residue feedstocks.

A key factor shaping production potential is the availability and evolution of feedstocks. The EU's feedstock mix has shifted significantly in recent years, with a marked rise in waste-based feedstocks and a relative decline in crop-based sources.

As of 2024:

- Crop-based feedstocks accounted for 39% of EU biodiesel inputs, with rapeseed oil maintaining its strong position at 34% of total use, the vast majority being used for the production of FAME.
- Waste-based feedstocks surpassed crops as the largest group, with UCO representing 24% of total feedstock use, followed by palm oil mill effluent (POME) at 13%.
- Annex IX Parts A and B feedstocks each contributed approximately 4.5 Mt, together comprising more than 50% of non-crop inputs.
- A residual share (6%) includes uncategorized feedstocks such as palm fatty acid distillate (PFAD) and Category 3 animal fats (animal by-products classed as having a low risk to humans and animals).
- HVO is mainly produced (more than 90%) from waste-based and Annex IX Parts A and B feedstocks.

Figure 6: Detailed breakdown of feedstocks used to produce FAME and HVO consumed in the EU-27 in 2025
(Source: EBB, 2026)^[23]



These trends reflect the growing relevance of sustainability criteria and the industry's capacity to diversify supply chains in line with EU mandates. The industry's flexibility in utilizing a broad range of feedstocks is a strength for future production expansion.

The recent evolution of the feedstock mix, heavy investments in capabilities to utilize more challenging feedstocks, and policy momentum point towards a continued shift in favour of waste and residue-based inputs.

The World Economic Forum report, *Clean Skies for Tomorrow. Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation* (2020),^[24] emphasizes the global potential of waste and residue-based feedstocks, such as UCO and animal fats, estimating that more than 40 million tonnes of renewable material is currently available. This is considered sufficient to meet the growing demand for FAME, HVO and SAF in the medium term. As more feedstocks will be mobilized, with the right policy signals and a stable regulatory framework, further volumes will be brought to the market.

Additionally, the report underlines the need to develop new value chains based on 'novel vegetable oils' derived from regenerative agriculture practices. These oils are suitable candidates for scaling HVO/HEFA production while preserving sustainability criteria. To this end, the upcoming guidelines for the certification of these feedstocks should provide a clear, robust and legally-binding framework, enabling economic operators and certification schemes to plan investments to deliver new supply chains and deliver feedstock volumes at the required scale.

Beyond Europe, the U.S. Department of Energy's *2023 Billion-Ton Report*^[25] confirms the vast technical potential of renewable carbon sources, including agricultural and forestry residues, wastes and new crops, to support large-scale biofuel production in the United States and globally.

The EU biodiesel and renewable diesel industry is well-positioned to scale up production to meet the GHG emissions reduction goals for the transport sector, contingent on a secure, renewable and diversified feedstock supply. Continued support for advanced waste collection systems, transparent sustainability certification, and investment in conversion capacity will be essential to realize this potential and continue to support the increasing transport sector demand, especially in hard-to-electrify segments such as the HDV sector.

For details of estimated feedstock availability, collection rates, key constraints and opportunities, see Table A2 in the Appendix.

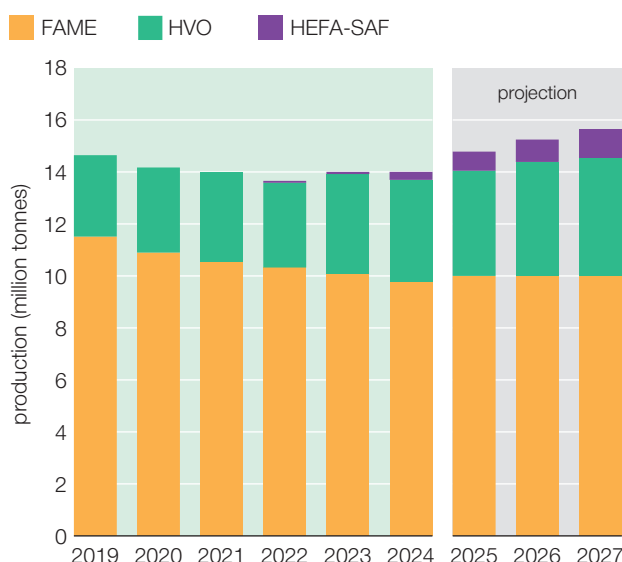
FAME and HVO production

The production of FAME in the EU has remained stable over recent years while the production of renewable HVO has increased, supported by evolving feedstock dynamics and a maturing policy framework under RED III^[14] and RED III^[18]. According to the 2025 EBB *Statistical Report*,^[10] the EU produced nearly 14 Mt of biodiesel and renewable diesel in 2024 (see Figure 7).

Several industrial projects are ongoing, and some have achieved a final investment decision (FID) to increase their EU production capacity and meet the increasing demand by 2028 and beyond.

Figure 7: Production of FAME, HVO, and SAF produced via the HEFA process (EU-27, million tonnes)

(Source: EBB, 2025)^[10]



Estimated use of FAME and HVO in the EU road transport sector

Biodiesel (FAME) continues to be one of the most accessible and immediately deployable solutions for reducing GHG emissions in the European road transport sector. Current EU legislation mandates B7 (7% FAME in diesel) as the standard protection grade. However, higher blends are already on the market in some countries, including France, Germany and Portugal, and are under active consideration in others. The revision of the Fuel Quality Directive (Directive 98/70/EC)^[21] and the adoption of RED III^[18] have opened the legal and technical pathways for broader B10 deployment across the EU.

Ongoing advancements in production, purification and additive technologies are enhancing the suitability of FAME blends above 10% without compromising fuel quality or engine durability. This was shown most recently in tests involving VW, the University of Coburg and AGQM (2025)^[26] where B10 performed as required from an emissions and engine oil quality perspective. In addition, CEN standard EN 16709²⁰ has for 10 years allowed up to 30% FAME blends in diesel used in captive fleets, which has also operated well. The adoption of B10+ blends could therefore represent a strategic step in reducing GHG emissions in the transport sector, leveraging existing biodiesel production capacity and supporting the transition to renewable alternatives by utilizing waste and residue feedstocks.

Beyond public pump grades, there is confirmed use of even higher biodiesel blends—such as B20, B30 and B100—within captive fleets in several EU member states. These include Belgium, France, Germany, Spain and Portugal, where specific segments such as logistics fleets or municipal operations are already integrating high-blend biodiesel in controlled conditions.

²⁰ European Standard EN 16709: Automotive fuels – High FAME diesel fuel (B20 and B30) – Requirements and test methods

A more ambitious policy and regulatory approach is recommended, including pilot programmes, certification pathways and revisions to fuel standards that enable higher FAME blending ratios. Such measures would unlock greater environmental benefits and accelerate the transition towards a more renewable energy system.

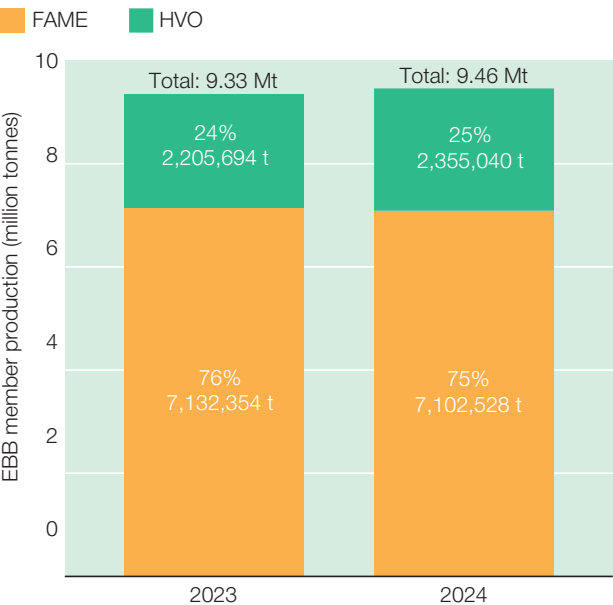
The fuel specifications for paraffinic diesel, including HVO, are outlined in CEN standard EN 15940. Provided that engines and infrastructures are compatible with these specifications, there is no reason why the proportion of HVO in diesel fuel blends cannot reach 100%. Indeed, pure/unblended HVO (HVO100) is already commercially available and widely accessible to consumers at service stations in several EU member states, including Italy, Germany, France, Spain and Austria. The number of pumps serving pure HVO is steadily increasing across Europe.

Moreover, HVO is fully compatible with all type-approved diesel engines and can be used without any engine modifications or further investments in current logistic and distribution infrastructures when blended in proportions meeting the EN 590 diesel fuel specifications (around 35% (v/v) for temperate climates and up to 65% (v/v) for severe winter grades). This makes it an immediate and viable solution to accelerating the energy transition in the mobility sector.

These cases show that biodiesel and renewable diesel are already meeting real transport energy needs under operationally viable conditions.

Figure 8: EBB member production of FAME and HVO (2023–2024)

(Source: EBB, 2025)^[10]



Biodiesel and renewable diesel are widely used in the European Union as key components of the renewable transport fuel mix. In the long run, they will have a substantial role, particularly in applications that are less suitable for electrification, including heavy-duty vehicles, long-distance haulage, and agricultural or construction machinery.

Lignocellulosic biomass and waste-based renewable diesel

Definition and application in vehicles

In addition to HVO, renewable diesel can be produced from lignocellulosic biomass and biowastes using thermochemical conversion technologies followed by upgrading process steps. This renewable diesel can meet the technical requirements of CEN standard EN 590 (when blended) or EN 15940 (as paraffinic diesel when used neat). It is fully compatible with existing logistics infrastructure (storage, pipelines, distribution) and diesel engines in passenger cars, and in heavy-duty and off-road applications.

Feedstock and production pathways

Renewable diesel hydrocarbons produced from lignocellulosic biomass (such as forest residues, agricultural residues, dedicated energy crops) and biowastes (paper, cardboard, wood waste, animal and mixed food waste, vegetal waste, municipal solid waste) can be produced via several technologies:

- **Gasification and Fischer-Tropsch synthesis:** Conversion of lignocellulosic biomass via gasification into synthesis gas (CO and H₂), followed by Fischer-Tropsch (FT) synthesis and subsequent hydroprocessing to produce diesel-range paraffins with very high cetane.
- **Pyrolysis and upgrading:** Thermal conversion of solid biomass to a pyrolysis oil (bio-oil), followed by hydroprocessing (on a stand-alone basis or co-processed in refinery units) to remove oxygen and other impurities.

- **Hydrothermal liquefaction (HTL) and upgrading:**

Conversion of lignocellulosic and waste-based feedstocks into biocrude in subcritical/supercritical water, followed by hydroprocessing (on a stand-alone basis or co-processed in refinery units). Operating under wet conditions makes HTL particularly suitable for feedstocks with high moisture content, as it eliminates the need for energy-intensive drying pretreatment required by other thermochemical conversion routes.

- **Alcohol-to-distillates (ATD) from biomass**

alcohols: Biomass-derived methanol or ethanol/butanol (from gasification or advanced fermentation of lignocellulosic sugars) converted via dehydration, oligomerization and hydrogenation to middle-distillate hydrocarbons suitable for use as renewable diesel or jet fuel.

Greenhouse gas emissions

Depending on feedstock production management and logistics, process energy input and source, and hydrogen source, lignocellulosic and waste-based renewable diesel can typically achieve 82–89% GHG savings vs the 94 gCO₂e/MJ fossil comparator established in the EU legislation.

Production output

Technology pathways from lignocellulosic biomass are being developed to scale up HVO production in the coming years. Fast pyrolysis is the most advanced, with a technology readiness level (TRL)²¹ of 8–9, with multiple units operating in Europe and producing bio-oils that are co-processed in refineries or used for industrial heat; stand-alone upgrading of these oils to transport fuels is less advanced (TRL 7). For the gasification and Fischer-Tropsch route, multiple subsystems have been proven at industrial scale; however, the technology is still

²¹ TRLs are a standardized measurement system originally developed by NASA and used to assess the maturity and commercial readiness of a specific technology: <https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/>

pre-commercial (TRL 6–8) for the integrated biomass-to-liquids pathway with no industrial scale projects passing the FID stage in Europe to date. Hydrothermal liquefaction to biocrude is at TRL 5–6. Technology for alcohol-to-distillates from biomass alcohols currently ranges from pilot stage to early-commercial maturity.

E-diesel

Diesel can also be produced synthetically using electricity, water and air. Two synthesis routes exist to produce e-diesel: firstly, the FT process, and secondly, methanol synthesis and further conversion of methanol to middle distillates (MTD)²²—typically ranging from C10 to C22, like diesel or kerosene.²³ Both routes are chemically well known and have a high technology readiness level,^[27] although no large-scale MTD plant is in operation at the present time. The difference between the two processes is that the FT process produces a number of by-products, such as naphtha or kerosene, and a refinery process is always required. These by-products can be used in the chemical industry, and in the maritime and aviation sectors. This leads to synergies with these sectors but reduces production volumes for a dedicated product. Following the methanol route, more e-diesel per energy input can be produced, and no traditional refinery process is required. Many e-fuel production plants are planned to follow the FT route (e.g. [Nordic electrofuel](#) and [Arcadia eFuels](#)) but also to follow the methanol route (e.g. [Hif global](#)). Several vehicle tests have shown that e-diesel can be used in blends with fossil diesel or biodiesel or as a pure product, including in [existing vehicles](#). E-diesel has a similar structure to existing products such as GTL and HVO/HEFA and it meets the requirements of CEN standard EN 15940 for paraffinic fuels.

Renewable fuels for gasoline engines

Bioethanol

Introduction and fuel definition

Bioethanol is the most widely produced biofuel in the world, with a global output of 130 billion litres, i.e. 66 Mtoe in 2024 (47% US, 28% Brazil, 8% China, 6% EU, 6% India, 5% rest of the world) according to S&P Global.^[5] It is mostly obtained by fermentation of sugars and starch contained in biomass, in biorefineries that often operate in synergy with sugar and starch factories producing conventional ethanol.

Ethanol's high-octane content (109) allows the ignition timing of an engine to be advanced to improve the engine's yield. Ethanol's heat of vaporization is 2.5 times lower than that of gasoline, allowing better charge air cooling which, in turn, can enhance an engine's power, efficiency and longevity. These characteristics make ethanol a good renewable fuel for petrol and hybrid petrol cars.

Today, bioethanol is only used in light-duty vehicles and light commercial vehicles.

In the aviation industry, the alcohol-to-jet (ATJ) pathway is under development, and the ReFuelEU Aviation regulation^[28] excludes the use of conventional biofuels in aviation. In the maritime industry, the FuelEU Maritime Regulation^[29] allows the use of conventional biofuels but does not acknowledge their CO₂ emissions reduction compared to fossil fuels. In the heavy-duty vehicle sector, Scania produced HDVs running on ED95 fuel (95% ethanol+5% pro-cetane additive) until 2023. Today, no original equipment manufacturer (OEM) produces an HDV designed to run on ED95 fuel.

²² MTD = methanol-to-diesel: a process used to convert methanol to middle distillates (i.e. hydrocarbon fractions that include kerosene, diesel fuel and jet fuel)

²³ C10 = an organic hydrocarbon chain containing 10 carbon atoms; similarly, C22 represents an organic hydrocarbon chain containing 22 carbon atoms.

In 2025, bioethanol is present in every unleaded petrol fuel in Europe:

- Up to 5% v/v ethanol in E5 (unleaded 95)
- Up to 10% v/v ethanol in E10 (unleaded 95–E10)
- Between 60% and 85% v/v ethanol in Ethanol-E85, average 75% v/v

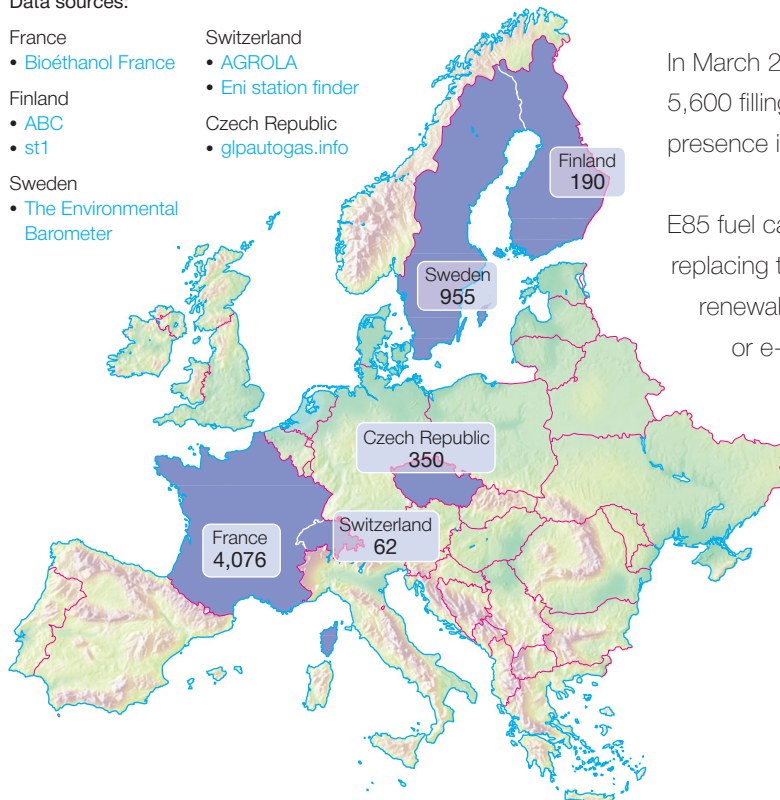
Standardization work has been finalized for an E20 petrol fuel containing up to 20% v/v ethanol. CEN Technical Standard CEN/TS 18227²⁴ for E20 petrol was published in December 2025.

A sizeable share of vehicles recently put into circulation in the EU (and the UK) may be broadly functional using petrol containing up to 20% ethanol (where the ethanol meets CEN standard EN 15376²⁵ and the petrol otherwise meets standard EN 228).²⁶ Further work is needed to complete the functionality and material compatibility assessment of the existing petrol fleet. At this time, and unless otherwise stated, manufacturers²⁷ can give no guarantee regarding compatibility, nor can they give any assurances regarding compliance with exhaust emission type-approval requirements in force at the time such new vehicles entered into circulation, or with periodic technical inspection requirements.

Figure 9: E85 fuelling stations in Europe

Data sources:

- | | |
|-------------------------------|----------------------|
| France | Switzerland |
| • Bioéthanol France | • AGROLA |
| | • Eni station finder |
| Finland | Czech Republic |
| • ABC | • glpautogas.info |
| • st1 | |
| Sweden | |
| • The Environmental Barometer | |



E10 is replacing E5 in a growing number of countries, and is now present in 21 European countries.

In March 2026, E85 fuel was available at more than 5,600 filling stations across Europe, with a significant presence in France, Sweden, Finland and Switzerland.

E85 fuel can easily become 100% renewable by replacing the average 25% fossil gasoline with renewable gasoline molecules, such as bionaphtha or e-naphtha co-products of SAF production.

²⁴ European Technical Standard CEN/TS 18227:2025: Automotive fuels – E20 petrol – Requirements and test methods

²⁵ European Standard EN 15376: Automotive fuels – Ethanol as a blending component for petrol – Requirements and test methods

²⁶ European Standard EN 228: Automotive fuels – Unleaded petrol – Requirements and test methods

²⁷ At the date of publication of this report, some vehicle manufacturers have confirmed that E20 petrol fuel is compatible for use in [some] older vehicles in circulation.

100% renewable E85 has already proven its viability in the retail market in California, where it is used by around one million flex-fuel vehicles. In 2022 it constituted one-third of E85 sales in California. In 2024, the French research organization IFPEN tested three types of renewable gasoline^[30] that could be used to replace the fossil gasoline in E85 fuel: (i) bionaphtha; (ii) e-naphtha (a co-product of e-SAF); and (iii) ethanol-to-gasoline (ETG). In all three cases, the pollutant emissions were very low compared to Euro 7 limits.^[31]

GHG emissions savings for bioethanol

In 2024, European producers of renewable ethanol achieved an average certified GHG intensity reduction rate of 81.6% compared to the EU fossil fuel comparator^[32] (see Figure 10). By reducing carbon

emissions from the boilers, by capturing the fermentation CO₂ from ethanol production, and by replacing fossil CO₂ in other sectors, European bioethanol producers continue to improve the GHG emissions reduction potential for bioethanol made in Europe.

According to the EEA/ETC-CM report, *Greenhouse gas intensities of transport fuels in the EU in 2023: Monitoring under the Fuel Quality Directive*,^[33] bioethanol incorporated in petrol fuels in 2023 led to an average GHG emissions reduction of 78.4% compared to gasoline.

Figure 10: Weighted average certified GHG emissions savings for EU renewable ethanol (% , RED I and II)
Source: ePure, 2026^[32]

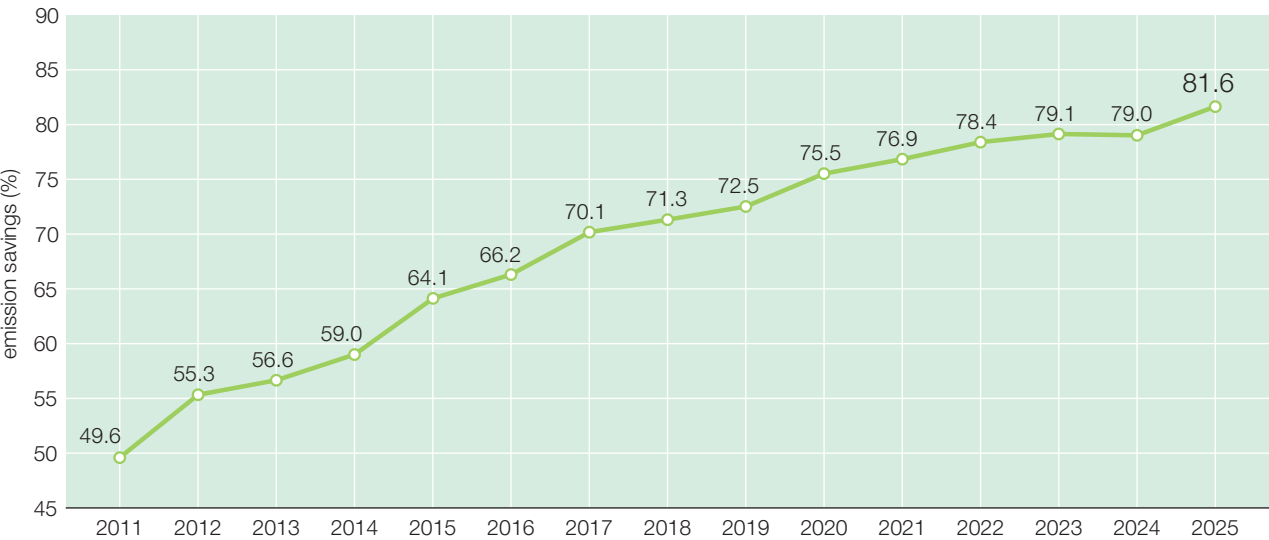
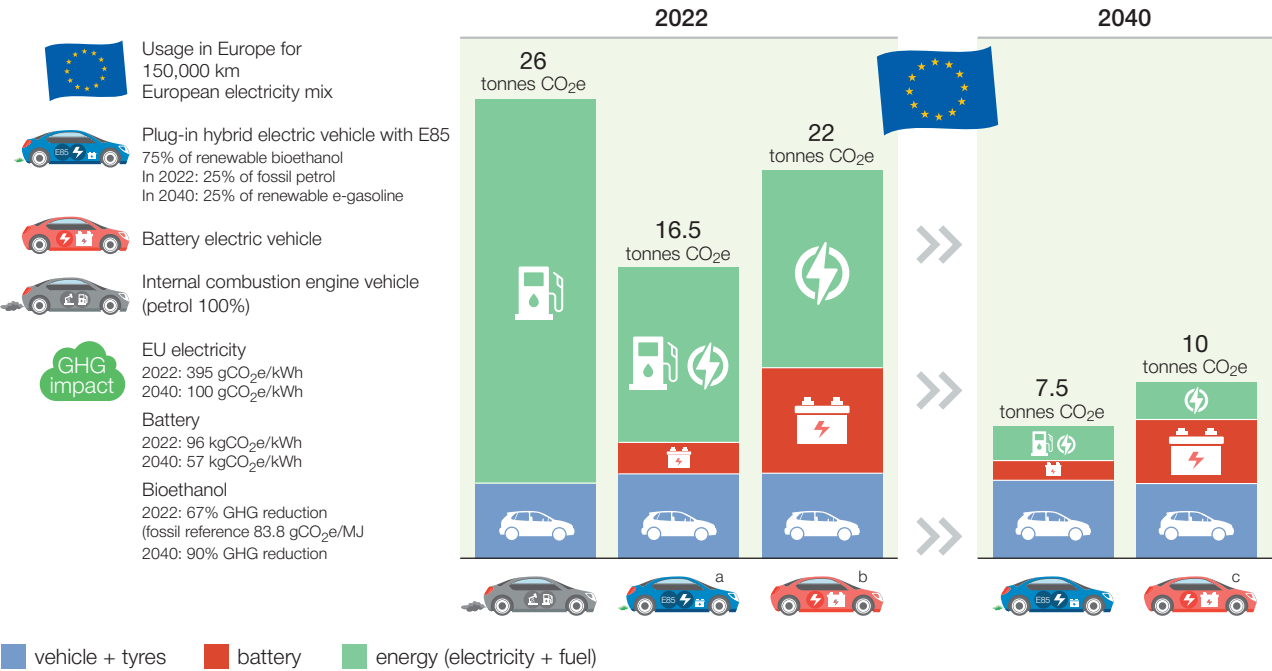


Figure 11: CO₂ emissions of new compact cars in Europe—C-segment (life-cycle analysis)

(Source: ePure, 2024b)^[30]



In 2022, a C-segment plug-in hybrid electric vehicle (PHEV) running on E85 fuel had the same CO₂e emissions in a life-cycle analysis as a battery electric vehicle (BEV) with French electric mix, and this will remain as good in 2040 with fully renewable E85 fuel (see Figure 11). With a 2022 European electric mix, the same PHEV running on E85 has lower CO₂e emissions than a BEV.^[34]

Fuel production—description of fuel pathways and feedstocks

Renewable ethanol is manufactured in biorefineries by fermenting sugars into alcohol. In the EU, these sugars typically come from a variety of agricultural sources such as wheat, corn, barley, rye, triticale and sugar beet for conventional ethanol production. The production of advanced ethanol uses mostly lignocellulosic feedstocks and residues (i.e. agri-residues such as rice and wheat straw, pre-harvest cane residue, corn cobs and stover, bagasse, etc.). Currently, the most commonly used feedstocks in Europe are corn, sugar beet and wheat.

The ethanol production process includes the following steps:

- **Extraction of sugars from feedstock:** The feedstock is broken down into fermentable sugars using either physical processing or innovative technologies such as enzymatic hydrolysis and pretreatment, depending on the type of feedstock.
- **Fermentation:** The sugars are transformed into an alcohol-water liquid and biogenic CO₂ (captured and purified).
- **Distillation:** Alcohol-water liquid is heated up to 80°C in order to separate the alcohol from the water. The raw alcohol obtained is 96% vol. alcohol.
- **Dehydration:** The raw alcohol goes through filters to remove the remaining water (in order for the ethanol fuel to burn correctly in the engine) and reach 99.7% vol. alcohol. The resulting product is called bioethanol.

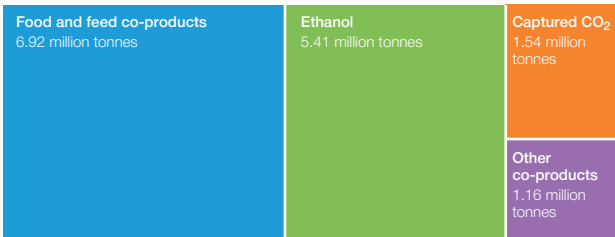
Ethanol biorefineries turn crops from European farmers into renewable ethanol for LDV fuels, while nutrient-rich co-products provide food and animal feed, thereby reducing the need for protein imports. In addition, the biogenic CO₂ released during the fermentation process can be used in fizzy drinks, and is increasingly being used in the production of e-fuels.

In 2024, bioethanol plants in Europe produced:^[35]

- 6.9 million tonnes of food and feed co-products;
- 5.4 million tonnes of ethanol; and
- 1.5 million tonnes of biogenic CO₂.

Figure 12: The main output of European renewable ethanol plants (million tonnes, commercial output)

(Source: ePure, 2025)^[35]



Approximately 90% of bioethanol produced in 2024 in Europe is conventional bioethanol.^[35]

In RED Annex IX, Part A feedstocks represent less than 10% of ethanol produced in 2024 in Europe. The definition of eligible fuels needs to include both advanced and conventional biofuels in order to ensure sufficient supply of renewable ethanol for gasoline and hybrid light-duty vehicles. Conventional biofuels and advanced biofuels targets are set in RED III.

Figure 13: Feedstock used to produce renewable ethanol (million tonnes)

(Source: ePure, 2025)^[35]



According to the EU Cereals market situation summary for 2025/2026, published by the European Commission, cereals used for bioethanol represented 4% of total cereals use in Europe.^[36]

Estimated use of bioethanol in the road transport sector

European biofuel production capacities plus imports from third countries (via trade agreements) could amount to around 13 million m³ bioethanol available in 2035. It is estimated that this would be sufficient to run 38 million flex-fuel PHEVs using E85 fuel in 2035 (15% of the European passenger car fleet) and, by 2050, 73 million PHEVs using E85+ (29% of the European passenger car fleet).

In the case of hybrid electric vehicles (HEVs, i.e. non-plug-in) with an average fuel consumption of around 6 litres per 100 km, it is estimated that the volume of ethanol available would be sufficient to run 22 million HEVs using E85+ in 2035 (9% of the European passenger car fleet) and 43 million HEVs in 2050 (17% of the passenger car fleet).

For further information on the projected availability of fully renewable E85+ fuel for the light-duty vehicle fleet see Table A3 in the Appendix.

Biomass-based renewable gasoline

Definition and application in vehicles

Renewable gasoline is a mixture of renewable hydrocarbons that meets the technical requirements of CEN standard EN 228 as a conventional mineral gasoline fuel. It is therefore fully compatible with current logistics systems and current petrol vehicles.

Feedstock and production pathways

Renewable hydrocarbons can be produced from different feedstocks and via different routes:

- **Ethanol-to-gasoline (ETG):** Bioethanol, produced as discussed in the previous section, is the feedstock for this process. The first stage of the ETG process is an endothermic alcohol decomposition reaction which produces ethylene and water vapour. The next stage consists of complex reactions involving the synthesis of renewable hydrocarbons from the ethylene. The chemical composition of the renewable hydrocarbons is the same as the chemical composition of gasoline, hence the final fuel is of an equivalent high quality and is compatible with current logistics systems and petrol vehicles.
- **Methanol-to-gasoline (MTG):** Renewable methanol, produced via the biomass route or the RFNBO route, is the feedstock for this process. The biomass route involves the gasification of solid waste residues, while the RFNBO route utilizes eligible CO₂ and renewable hydrogen. From both routes, a synthesis gas (CO and hydrogen) is obtained. The key steps of the MTG process include catalyst reaction, olefins oligomerization,²⁸ and subsequent formation of paraffins and aromatics. As with the ETG process, the chemical composition of the renewable hydrocarbons is the same as the chemical composition of gasoline, hence the final fuel is of an equivalent high quality and is fully compatible with current logistics systems and petrol vehicles.
- **Fischer-Tropsch (FT):** The feedstock for the FT process is a synthesis gas (CO and hydrogen) which could be obtained via the MTG route described above. The FT process involves a chemical reaction that converts the synthesis gas into liquid hydrocarbons, including gasoline, using a transition metal catalyst, most commonly iron or cobalt.

²⁸ Oligomerization is a process used in the petroleum refining industry, in which olefins are converted to fuel-range hydrocarbons.

- **Bionaphtha processing:** Bionaphtha is typically derived as a by-product from the HVO process used to create products such as renewable diesel and SAF. The bionaphtha is used as a component for creating renewable gasoline, either by blending with fossil gasoline, or through reforming and isomerization to produce a high-octane gasoline.
- **Other routes:** Two additional routes for producing renewable hydrocarbons that can be used as a blending component to obtain a final renewable gasoline include:
 - **Hydrotreatment of lipid biomass:** This is the same route as the HVO process, and can be used to produce bionaphtha which can be processed to produce a drop-in fuel (see *Bionaphtha processing*, above).
 - **The biofarming process:** This involves catalytic technology that converts plant-derived sugars into renewable drop-in fuels, and compounds that are chemically identical to petroleum-derived products.

Greenhouse gas emissions

Depending on the feedstock used and the GHG emissions of the energy used in the process, renewable hydrocarbons can achieve GHG savings of 80–95% relative to the EU's fossil fuel comparator of 94 gCO₂e/MJ specified in RED II.^[14]

Production output

Currently, only a few industrial production plants are in operation using the MTG and ETG routes. Not all of these MTG production plants are currently using the technology to produce renewable gasoline, as some are using 'mineral methanol' (i.e. fossil-derived methanol) as a feedstock for producing non-renewable fuel. These plants could, however, be fed with renewable methanol to produce renewable gasoline.

Automotive gasoline is difficult to use in applications other than passenger cars, mainly due to its short shelf life. For that reason, the regulatory framework is a key element in promoting the increase in renewable gasoline production capacity, and the industry is continuing to invest in technology to improve production capacity and introduce new feedstocks and production routes.

Figures 14 and 15 on page 30 show the production processes for renewable fuels from methanol synthesis and Fischer-Tropsch synthesis, respectively.

Market availability

While 100% renewable gasoline is fully compatible with existing petrol vehicles when it meets the EN 228 fuel standard, its availability at service stations remains limited.^[37]

Figure 14: Renewable fuels production using methanol synthesis

(After van Dyk and Saddler, 2021^[38] and Bube et al., 2024^[39])

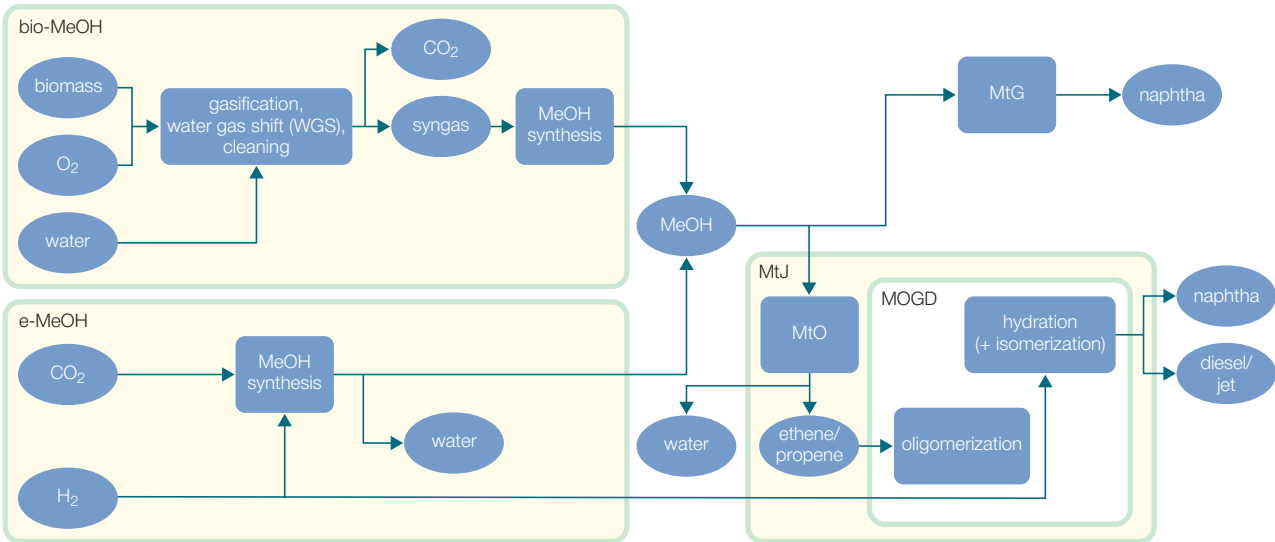
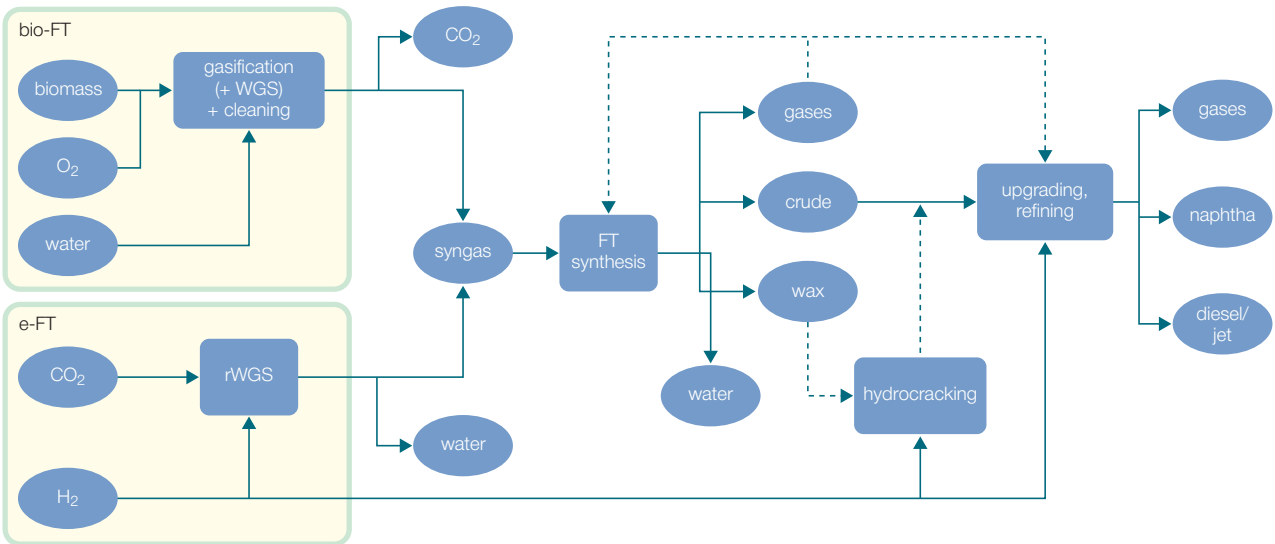


Figure 15: Renewable fuels production using Fischer-Tropsch synthesis

(After van Dyk and Saddler, 2021,^[38] de Klerk, 2011^[40] and Ayala-Cortés et al., 2025^[41])



Renewable fuels for gaseous-fuelled engines

Renewable liquid gas

Liquid gas, often referred to as 'autogas' when used as a transport fuel, offers a cleaner-burning, versatile alternative to conventional fuels. It primarily consists of propane and butane, which are stored as liquids under moderate pressure and revert to gas upon release. In 2023, autogas was used to power more than

8.2 million cars and 300,000 commercial vehicles in Europe, and was available at 32,000 filling stations. The EU's goal of net zero GHG emissions by 2050 has led to the emergence of renewable alternatives to fossil LPG—most notably renewable liquid gases (rLG), which include renewable LPG (rLPG) and renewable dimethyl ether (rDME). These fuels are chemically similar to conventional LPG, which allows them to be used as drop-in solutions for the existing autogas fleet and infrastructure.

Definitions

Liquid gas (LPG):

- Liquid gas, commonly referred to as autogas or LPG, primarily comprises propane (C_3H_8) and butane (C_4H_{10}). Under relatively low pressure (6–8 bar at 20°C) it remains in liquid form, but converts to a flammable gas when released at atmospheric pressure.
- Dimethyl ether (DME), an emerging renewable alternative, shares similar properties with LPG. DME is an oxygenated hydrocarbon with similar combustion characteristics to LPG. Chemically akin to propane and butane, DME remains in liquid form under moderate pressure and is compatible with existing LPG infrastructure. When blended up to 12% by mass, DME can be used in LPG engines without requiring modifications.

Renewable liquid gas (rLG):

- Renewable liquid gases include:
 - renewable propane, butane, bio-LPG (biopropane) and e-LPG, known collectively as renewable LPG (rLPG); and
 - renewable dimethyl ether, referred to as renewable DME (rDME).

- Renewable LPG can be produced from biological sources, where it is known as bio-LPG (also known as biopropane); and potentially from renewable electricity and CO_2 , where it is referred to as e-LPG.
 - Currently, bio-LPG is mainly sourced from HVO plants and other biofuel processes, where it is a by-product of the production of renewable diesel or SAF.
 - e-LPG (a form of rLPG and an RFNBO) is a renewable, non-biogenic fuel synthesized from CO_2 and hydrogen produced via renewable electricity-powered electrolysis. It can be produced as a co-product of hydrocarbon synthesis processes, such as FT or MTG, or as a primary product from processes that directly synthesize LPG by combining CO_2 and hydrogen. e-LPG relies on renewable electricity to generate hydrogen and can utilize captured CO_2 from industrial emissions or direct air capture, ensuring a closed carbon cycle.
- rDME can be produced from gasification of waste wood and residues. e-DME relies on renewable electricity to generate hydrogen and can utilize captured CO_2 from industrial emissions or direct air capture, ensuring a closed carbon cycle.

Greenhouse gas emissions: rLG vs conventional LPG

Renewable liquid gases can cut GHG emissions by more than 80%, depending on the feedstock and production pathway. Table 3 illustrates the estimated CO₂ emissions savings in Europe when compared to RED fossil fuels.

Such dramatic GHG reductions provided by rLG offer an immediate path to reducing the climate impact of the transport sector, which is invaluable where electrification is not feasible in the near term.

Table 3: Estimated CO₂ emissions savings from rLG in Europe in 2040 and 2050

Year	rLG for transport (kt, estimates)	GHG savings (ktCO ₂ e)
2040	~1,500	~20,467
2050	~5,500	~74,005

Note: these figures correspond to median values of emission reductions aligned with RED thresholds, and are calculated as follows:

- The lower bound was calculated using the heating threshold (80% saving against a comparator of 80 gCO₂e/MJ, hence a saving of 64 gCO₂e/MJ).
- The higher bound was calculated using the transport threshold (70% saving against a comparator of 94 gCO₂e/MJ, hence a saving of 65.8 gCO₂e/MJ).
- The median value was calculated from the upper and lower values.

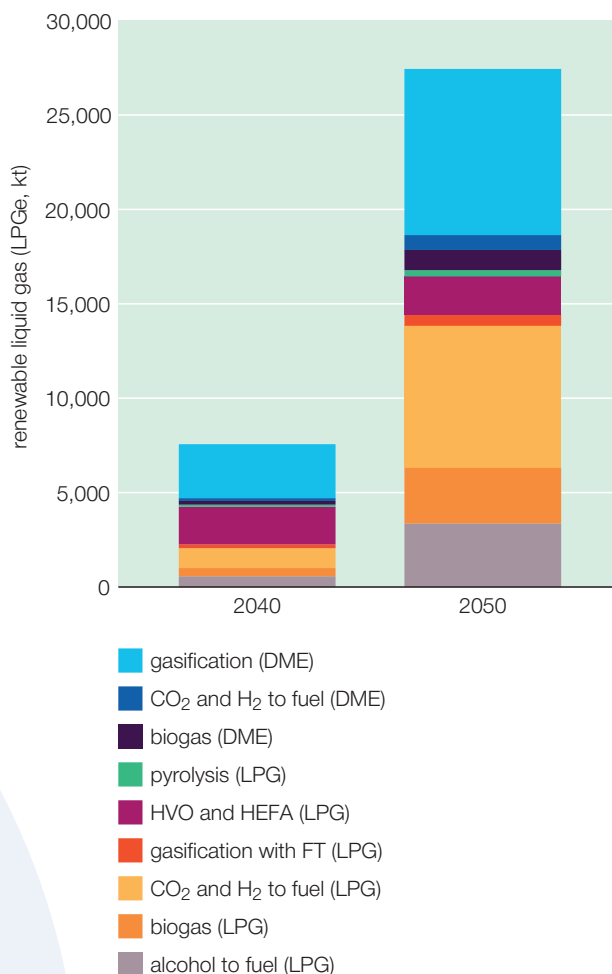
Feedstocks and production pathways

Key feedstocks include:

- **Lipids** (UCO, tallow, virgin oils)—the main feedstock for the HVO/HEFA process from which rLPG is derived.
- **Biogas**—the source for rLPG and rDME produced via methanation, reforming and synthesis.
- **Ethanol**—processed via alcohol-to-fuel pathways.

Figure 16: Contributions to rLG production in 2040 and 2050

(Data according to the 'High supply scenario' (supportive policy frameworks and technology advancement) in the Alder BioInsights (formerly NNFFC)/ Frazer-Nash study published by Liquid Gas Europe in 2025^[42])



Production output and transport allocation (2040–2050)

By 2040 and 2050, production of renewable liquid gas is projected to expand significantly under a high-policy-support scenario, according to Liquid Gas Europe's 2025 report^[42] (see Table 4). This assumes that current LPG consumption patterns will continue, with 20.8% of LPG being used for transport. The actual share could increase as rLG is adopted to reduce fleet emissions, especially among light commercial and municipal vehicles.

Based on the feedstock conversion efficiency for each pathway, Alder BioInsights (formerly NNFC) and Frazer-Nash calculated the feedstock volumes required to meet the production outlook (excluding CO₂ and hydrogen) taking market competition and other feedstock uses into account. Table 5 outlines the

feedstock requirements. The 'consumed' figure (in kilotonnes) represents the amount of feedstock needed to produce both the target fuel and the associated rLG in by-production pathways (or needed to produce just the rLG in the case of direct pathways).

The total (kt) for each feedstock group is the total amount of feedstock available before any competition factor is applied. While the proportions of the total feedstock estimated to be available for lipids and ethanol are high, it should be noted that the pathways that use these feedstocks are those designed to produce another biofuel (e.g. SAF), with the rLG being produced as a by-product of the process. The total (kt) for each feedstock group is the total available before any feedstock competition factor is applied (Liquid Gas Europe, 2025).^[42]

Table 4: Projected expansion of renewable liquid gas

Year	Total rLG production (kt LPGe)	Potential for transport (%)	rLG for transport (est. kt)
2040	7,543	~20%	~1,500
2050	27,389	~20%	~5,500

Table 5: Renewable liquid gas feedstock scenarios for 2040 and 2050

(Source: Liquid Gas Europe, 2025)^[42]

Group	2040			2050		
	Consumed (kt)	Total (kt)	Proportion (%)	Consumed (kt)	Total (kt)	Proportion (%)
Wastes	27,671	642,843	4.3	90,660	638,854	14.2
Lipids	29,876	44,008	67.9	29,876	44,582	67.0
Ethanol	2,768	20,294	13.6	16,764	21,901	76.5
Biogas	2,372	216,841	1.1	13,379	287,250	4.7

Application in vehicles

Modern engine technologies support a seamless transition to rLG via the following technologies:

- **Vapour port injection (VPI)**—dominant in retrofitted vehicles.
- **Liquid port injection (LPI)**—delivers LPG in liquid form, enabling improved combustion and efficiency.
- **Liquid direct injection (LDI)**—the future trend, offering high performance with advanced emissions control.

These systems require no fundamental modification for renewable LPG or DME blends, making rLG a true drop-in fuel for both existing and new autogas-powered vehicles.

Conclusion

Renewable liquid gases—particularly rLPG and rDME—are poised to become critical enablers of low-carbon mobility across Europe. Their compatibility with the existing autogas infrastructure, combined with deep life-cycle emissions reductions, positions them as a near-term solution for reducing transport emissions.

By 2050, a scaled-up rLG industry could supply the entire transport sector's current LPG demand with renewable alternatives. However, realizing this potential hinges on:

- **Clear policy recognition** of rLG as an investment in renewable technologies that is eligible for sustainable finance.
- **Life-cycle-based emissions accounting** in transport legislation.
- **Stable and harmonized regulation** supporting feedstock access, investment certainty, and fuel-neutral competition.

In short, renewable liquid gas can drive climate progress in the transport sector, provided policy frameworks can live up to their potential.

Renewable methane

Introduction and fuel definition

The transport sector already contributes to the climate and sustainability targets through the replacement of natural gas with renewable methane from biological origin, which is currently well-established (bio-CNG, bio-LNG), or from non-biological origin (e-methane) for which the outlook is positive in the mid to long term.

Renewable methane of biological origin

Biogas is a mixture of methane, CO₂ and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment. The precise composition of biogas depends on the type of feedstock and the production pathway.

Biomethane (also known as 'renewable natural gas') is a near-pure source of methane produced either by 'upgrading' biogas (a process that removes any CO₂ and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation. For road transport, biomethane can be stored onboard in the gaseous phase at a pressure of approximately 200 bar (bio-CNG), or in the liquid phase (bio-LNG) which has the advantage of a higher energy density and is characterized by a very high degree of purity. Bio-LNG is currently used in heavy-duty vehicles, and its adoption is increasing in the maritime transport sector and in key global ports.

Renewable methane of non-biological origin

The e-fuel family includes e-methane, which is produced through a power-to-gas conversion technology combining renewable hydrogen with CO or CO₂.

General properties and GHG emissions of biomethane

Biomethane prevents emissions across the whole value chain, in the following main ways:

- Biomethane avoids emissions in the atmosphere that would otherwise occur naturally.
- Biogas and biomethane displace fossil fuels as energy sources.
- The digestate resulting from the production process can be used as biofertilizer and reduces demand for the carbon-intensive production of mineral fertilizers.

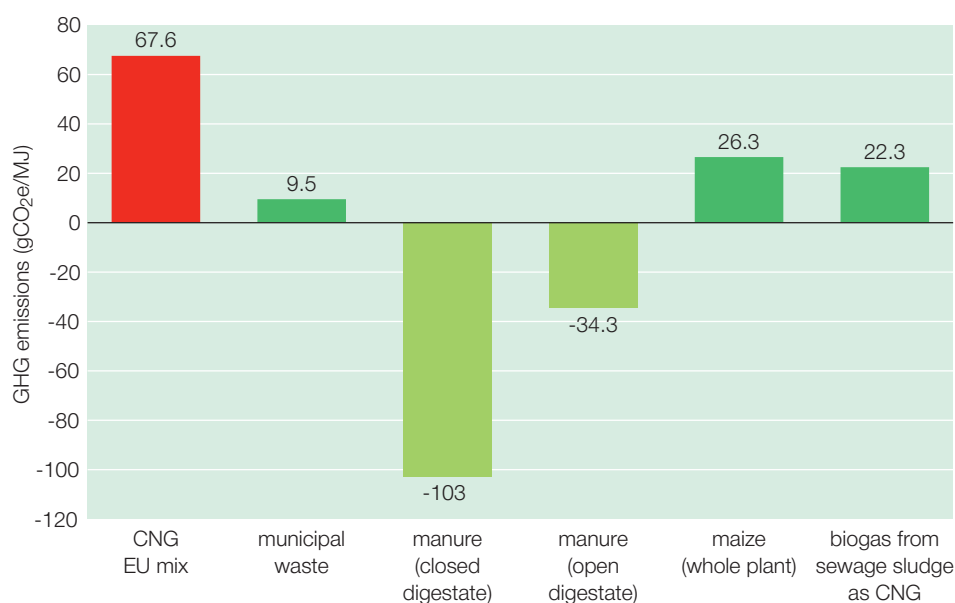
Figure 17 shows the GHG emissions of CNG and bio-CNG derived from specific pathways (similar values apply to LNG and bio-LNG).

The GHG emissions of bio-CNG and bio-LNG calculated over the energy cycle (well-to-tank including combustion) are much lower than the corresponding fossil fuel (first value on the left in Figure 17). When derived from specific feedstocks, such as manure, the resulting emissions can even be negative.

Since the composition of bio-CNG and bio-LNG is the same as that of CNG and LNG respectively, and as both meet the requirements of CEN standard EN 16723 Parts 1 and 2,^{29,30} bio-CNG and bio-LNG are drop-in solutions for gaseous-fuelled vehicles and can be directly used in transportation. The adoption of the concept of the 'EU interconnected gas system' by RED allows renewable methane to reach all potential users through the existing gas transport and distribution networks.

Figure 17: GHG emissions of CNG and bio-CNG derived from specific pathways (well-to-tank including combustion emissions, gCO₂e/MJ)

(Data from Prussi et al., 2020)^[43]



²⁹ European Standard EN 16723-1: Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network – Part 1: Specifications for biomethane for injection in the natural gas network

³⁰ European Standard EN 16723-2: Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network – Part 2: Automotive fuels specification

Fuel production processes for renewable methane

● Biomethane

Biomethane is produced from a diverse range of feedstocks with two main technologies:

1. Production of biogas, which is then upgraded³¹ to biomethane: biogas can be produced by:
 - Anaerobic digestion (the most popular process today): organic material, in sealed containers, is broken down by naturally occurring microorganisms.
 - Landfill gas recovery systems: the decomposition of municipal solid waste under anaerobic conditions at landfill sites produces biogas.
2. Gasification, which includes:
 - Thermal gasification (or pyrogasification): woody biomass is treated at high temperature and pressure, producing a mixture of gases, after which the methanation process utilizes a catalyst to promote a reaction between the gases to produce methane.
 - Hydrothermal gasification (i.e. supercritical water gasification): this process is particularly well suited to the treatment of water-based organic wastes.

The most important feedstocks are for anaerobic digestion,^[44] and include: agricultural residues, animal manure, biowaste, industrial wastewater, sequential crops, permanent grassland, roadside verge grass, and sewage sludge. Feedstocks for thermal gasification include: forestry residues, landscape care wood, municipal solid waste, prunings and wood waste.

● Synthetic methane (e-methane)

In the category of RFNBOs there are electro-fuels (e-fuels), where hydrogen from renewable sources is combined with CO₂ in a process called methanation (i.e. the Sabatier process) to produce e-methane which, in liquid form, is referred to as e-LNG. Synthetic gas can be produced without any by-products. The existing gas grid can be used to distribute e-methane as well as biogas. In addition, an increasing number of LNG carrier ships and terminals are being installed.

The availability of feedstocks and the potential for renewable methane production

● Biomethane

The production of biomethane has increased over recent years. Various factors, such as the increase in separated waste collection, the more efficient use of agricultural residues and animal manure, and the improvements in gasification technology, will contribute to further increasing the production of biomethane to satisfy the European demand in various sectors.

In 2023, Europe produced 22.1 bcm (billion cubic metres) of biogas and biomethane combined^[44] which corresponds to 7% of the total EU natural gas consumption in 2023. Around 4.9 bcm of biomethane was produced from upgraded biogas.

2030 and 2050 potential

The growth potential for biomethane is considerable. A Gas For Climate study^[13] estimated that the potential production of biomethane in the EU-27 plus Norway, Switzerland and the UK could reach 44 bcm in 2030 and 165 bcm in 2050.

³¹ The upgrading process removes any CO₂ and other contaminants.

The 2030 potential production is higher than the 35 bcm mentioned in the RePowerEU plan (2022),^[45] but the enabling conditions will need to be unlocked through clear political engagement. The 2050 potential represents up to 40% of the gas consumed in the EU in 2021. Assuming a reduced gas demand, biomethane will be able to cover up to 60% of gas demand by 2050. Such potential could lead to the creation of 465,000 new jobs by 2030 and more than 1.7 million jobs by 2050.

2040 potential

In 2040, Europe could produce 111 bcm of biomethane. This potential is made up of 74 bcm of anaerobic digestion (67% of the total) and 37 bcm of thermal gasification (33% of the total). Table 6 summarizes the potential production of biomethane in the next decades.

Table 6: Potential production of biomethane (bcm)

(Data from Gas for Climate, 2022^[13] and European Commission, 2022^[45])

Region	2023 (actual)	2023 (potential)	2040 (potential)	2050 (potential)
Europe	4.9	44	111	165
EU-27	4.1	40	101	150

● Synthetic methane (e-methane)

Almost all of the world's power-to-methane plants are located in the EU. In late 2018, 11 power-to-methane plants with a capacity of around 7 MW of methane were in operation in the EU. If additional plants under construction, planned and announced are also taken into account, production capacity could reach more than 16 MW of methane.^[46]

Estimated use of biomethane in the road transport sector

The current uses of biomethane differ from country to country, but at the EU level, the average usage values are 23% in transport, 17% in buildings, 15% in power generation, and 13% in industry.^[47]

The most promising application of biomethane in road transport is the propulsion of HDVs. Eurogas estimated the amount of energy required to power different proportions of the HDV fleet based on publicly available data.^[48,49] Table 7 shows the energy demand and share of biomethane required relative to the total potential biomethane production.

Table 7: Share of biomethane needed to power a portion of the EU heavy-duty vehicle fleet

(Based on data from ACEA^[48] and Eurostat^[49])

	2030	2040	2050
HDV fleet share powered by biomethane (%)	1%	5%	10%
Biomethane needed (bcm)	1.1	5.3	10.7
Energy demand from biomethane (Mtoe)	0.95	4.55	9.2
Biomethane required for HDVs (percent of total potential production)	2.7%	5.3%	7.1%

The main takeaway is that the quantity of biomethane needed to run a portion of the HDV fleet is a very small proportion of the total potential production. In 2030, 1% of the HDV fleet requires 2.7% of the potential production, and in 2040, 5% of the fleet requires 5.3% of the potential production. Finally, in 2050, powering 10% of the HDV fleet requires only 7.1% of the potential production (see Table 7).

For the small (but by no means negligible) fraction of light-duty vehicles powered by biomethane, it is estimated that the total energy demand from biomethane in 2030, 2040 and 2050 will be 2.2, 5.3 and 9.6 Mtoe, respectively. Due to the small share of biomethane needed for the transport sector, compared with the total potential production, the risk of competition with other sectors for the available biomethane is very low.

RFBNOs/e-fuels

Overview

Renewable fuels of non-biological origin (RFNBOs), commonly referred to as e-fuels, are produced from renewable hydrogen and renewable CO₂. For road transport, these encompass e-diesel, e-gasoline, e-LPG, e-DME³² and e-methane. Their sustainability depends on the use of renewable electricity, additionality requirements,³³ temporal and geographic correlation, and the supply of CO₂ from biogenic or direct air capture pathways (EU regulations currently require industrial CO₂ streams to be phased out by 2041). RFNBOs can achieve GHG reductions of 70–95% compared with fossil fuels, depending on the source of the electricity and CO₂ inputs. They are fully compatible with existing vehicle systems and fuel transportation and storage logistics, making them attractive options for a smooth transition to low-carbon fuels.

GHG emissions of e-fuels and the requirements of RED legislation

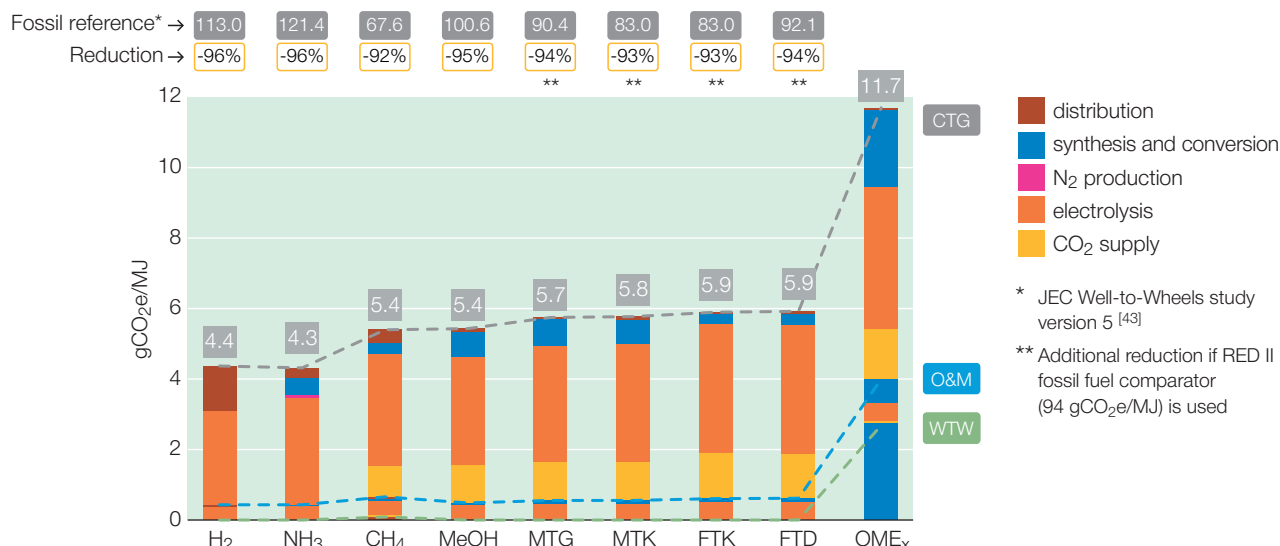
According to the RED, all e-fuels must meet a GHG emissions reduction of at least 70% compared to fossil fuels. In a best-case scenario, according to an exhaustive study by Imperial College/Concawe,^[3] a holistic life-cycle analysis has shown that a GHG emissions reduction of up to 95% is possible (see Figure 18 on page 39). In RED legislation, e-fuels are described as 'renewable fuels of non-biological origin'. The legislation also defines production and sustainability criteria, such as the use of renewable electricity and renewable carbon sources. Two 'delegated acts'^[50] of the RED stipulate that grid-connected e-fuel plants are only allowed to use additional renewable electricity (from installations not older than 36 months) and need to prove a temporal correlation (hourly from 2030 onwards) between the electricity generation and consumption in the same price bidding zone. The CO₂ has to come from ambient or biogenic sources. Industrial point sources are only allowed until 2041 and are required to be established in an effective carbon pricing system. This currently represents a real challenge for e-fuel production due to the associated increased costs.

³² Renewable dimethyl ether

³³ Requirements for hydrogen producers to use only electricity sourced from new, dedicated renewable sources

Figure 18: Cradle-to-grave GHG emissions of different e-fuel pathways (Case: North EU, 2050)

(Source: Concawe, 2024^[27])



Description of different feedstocks and resulting fuels

E-fuel production is based on the production of hydrogen. It involves an electrolysis process that breaks down water (e.g. seawater from desalination plants) into its components of hydrogen and oxygen. For this process and for further production steps, electricity is required.

In a next process step, with the aid of processes such as syngas production and Fischer-Tropsch synthesis, or methanol synthesis, the hydrogen is combined with CO₂ extracted from the air or other sources, and is converted into an energy carrier, i.e. an e-fuel. Because the production of e-fuels uses electricity, the procedure is known as a Power-to-X (or PtX) process: electricity is converted into a synthetic liquid or gaseous fuel (the 'X' in PtX) that is easy to store and simple to transport. Gaseous synthetic fuel can also be produced via a methanation process known as the Sabatier process.³⁴

After processing in refineries or undergoing further conversion, for example via the methanol-to-gasoline (MTG) process, the resulting e-fuels can include e-gasoline, e-diesel, e-methanol and e-gas. E-fuels are chemically identical to conventional fuels, and can therefore be used as drop-in replacements for fossil fuels. Moreover, due to their drop-in capability, e-fuels can be blended with conventional fuels and biofuels in any ratio, meeting the existing standards for gasoline (EN 228) and diesel fuels (EN 15940, EN 590). They can also be mixed with other renewable fuels (synthetic e-fuels), provided that the EN 228 and EN 590 specifications are met.

E-fuels are fully compatible with existing logistics, distribution and refuelling infrastructures, such as tank farms, tank lorries, pipelines and filling stations. These facilities can continue to be used with e-fuels, reducing the need for additional investment in the infrastructure.

³⁴ The Sabatier process is a specific type of methanation which involves a catalytic thermochemical reaction in which purified CO₂ reacts with H₂ over a metal catalyst at elevated temperature and pressure to produce synthetic methane (e-methane) and water.



Hydrogen

Green hydrogen is the first and simplest RFNBO. Hydrogen can be used directly in fuel cells or combustion-engine vehicles if a hydrogen infrastructure exists, and green hydrogen can replace fossil hydrogen in refineries. Europe has already invested about USD 5 billion in low-carbon hydrogen.^[51] Refineries are the easiest early large-scale outlet because they already use hydrogen, but they cannot scale into a long-term solution for the RFNBO market due to limited substitution potential, infrastructure bottlenecks, shrinking fossil fuel demand, and fragmented national rules. As a result, RFNBOs supplied via refineries are estimated to cover only 2 to 4 percent of transport fuel demand. Many investments in refineries are already taking place, which indicates that hydrogen is one of the first use cases of RFNBOs in the transport sector. For example, in July 2025, Air Liquide announced an FID to provide green hydrogen to TotalEnergies in the Netherlands and Belgium^[52] and Repsol announced FIDs on three green hydrogen projects^[53] over a 10-month period. Investments in green hydrogen are also under way by Shell in The Rhineland and BP in Lingen.

A further application is the co-processing of RFNBO hydrogen in the production of biofuels such as HVO and FAME, which is hydrogen-intensive and growing rapidly. The IEA estimates hydrogen demand for biofuels to be more than 27 TWh in 2025, potentially rising to 47 TWh by 2030, supported by synergies such as biogenic CO₂ access and existing fuel infrastructure. However, refinery and biofuel routes alone will likely be insufficient to meet rising EU quotas, and Europe will increasingly need to rely on RFNBO imports from regions with abundant renewable energy.

Gasoline

The production of synthetic gasoline requires the same ingredients as e-diesel. The production of syngas followed by the Fischer-Tropsch process, as well as methanol synthesis, can both be used to produce e-gasoline. In addition, the MTG process involves a further, different method of conversion, using a technology which is just as mature as the methanol-to-diesel (MTD) process. MTG technology involves a multistage process to convert methanol into gasoline, at operating temperatures of 300–400°C and pressures ranging between 10–30 bar. MTG technology was first developed by Mobil in 1980, and has been proven in commercial operation in some large-scale projects. The first commercial application took place in New Zealand in 1985,^[54] although that project was later discontinued for economic reasons. Today, the Haru Oni project by Hif Global in Chile is the first fully operational e-fuels facility, using the MTG process to produce around 130,000 litres of e-gasoline per year.^[55] In October 2023, Aramco and ENOWA announced plans to install MTG facilities in ENOWA's 'Hydrogen Innovation and Development Center' in Neom, Saudi Arabia,^[56] utilizing ExxonMobil technology.^[57] Development and construction of this demonstration plant is currently under way, and will have an e-gasoline production capacity of 1.5 KTA per year.

Estimated use of e-fuels in the EU road transport sector

E-fuel production is still in a pre-commercial phase. According to the IEA, more than 200 e-fuel projects are currently under development around the world.^[58] A report published by the eFuel Alliance in cooperation with Porsche Consulting in 2026^[12] highlights that more than 300 e-fuel projects are in development worldwide, representing a potential combined production capacity of 16 Mtoe of e-fuels (equivalent to approximately 20 billion litres of gasoline equivalent) and an estimated EUR 550 billion in investment potential, with strong

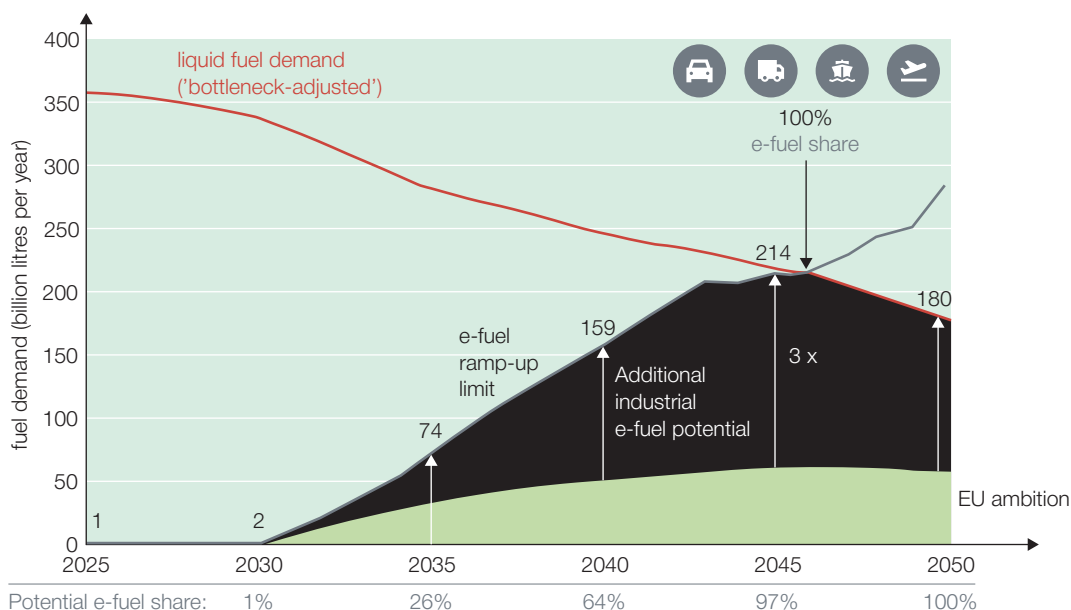
growth expected particularly in China, South America and Europe. The report also provides an updated industrial ramp-up assessment of potential e-fuel supply for the European Union, based on projections of e-fuel capacity evaluated on a global scale and adjusted to account for the forecast demand from other regions. The assessment showed that a global industrial ramp-up of e-fuel production could potentially provide the EU with around 74 billion litres by 2035, and by 2040 this could reach 159 billion litres—equivalent to approximately 64% of EU liquid fuel demand under a delayed ('bottleneck-adjusted') powertrain transition, where electrification progresses more slowly (see Figure 19). This potential significantly exceeds earlier estimates and highlights that industrial supply chains, rather than resource availability, are the main constraints. It also exceeds the potential announced by the EU in their 2040 climate target Impact Assessment Report.

However, according to the eFuel Alliance/Porsche Consulting study, only 6% of the announced capacities have reached FID, highlighting the persisting financing challenges. It is expected that the rate of FIDs will increase in future due to advancing political frameworks. With demand driven by the implementation of RED III surpassing 37 TWh (3.2 Mtoe) when combined with the ReFuelEU Aviation regulation, a tangible market pull exists. Some Member States, including Germany, Belgium and Spain, are considering long-term RFNBO quotas until 2040.

In their Global PtX Atlas, German research institute Fraunhofer IEE and the University of Kassel demonstrate that, in the long term, sufficient potential production capacity could be built up, with a potential for 85,000 TWh (7,300 Mtoe) of e-fuel production outside of Europe.^[59]

Figure 19: Annual liquid transport fuel demand in the EU in the 'bottleneck-adjusted' scenario, and e-fuel ramp-up for the 'EU Ambition' vs 'Industrial eFuel Potential' scenarios. Scope: gasoline, diesel, fuel oil, methanol, ammonia and jet fuel.

(Source: eFuel Alliance and Porsche Consulting, 2026^[12])



The 2026 eFuel Alliance/Porsche Consulting study confirms that such global potential is not a limiting factor; instead, the key constraints are equipment availability, renewable electricity infrastructure, and electrolyser supply chains.

Many potential production sites are located in rural areas within the wind or sun belt around the world, and large-scale projects will be built in regions with an abundance of renewable electricity generation, e.g. in sunny and windy regions around the globe. The use of renewable electricity for e-fuels should be additional to that required to supply local electricity grids with clean, renewable energy. Since liquid and gaseous fuels can be easily stored and transported, e-fuels do not need to be produced within Europe. As mentioned above, the Fraunhofer Global PtX Atlas suggests that up to 85,000 TWh of e-fuels could be produced outside of Europe, which would exceed the energy demand of the global transport sector (35,000 TWh). It is also possible that e-fuels could be sourced from more countries than those which currently export fossil fuels; for example, only a few resource-rich nations currently export fossil fuels, while almost any country with abundant wind, solar or hydro resources could potentially become an e-fuel exporter. Chile, Australia and Canada are already established exporters of e-fuels, and are likely to hold a strong position in the market due to their abundant natural resources and existing export infrastructure.

Conclusion

Conclusion

This assessment shows that Europe's renewable feedstock base, coupled with rapidly advancing RFNBO capacity, will be able to meet the EU road transport sector's demand for liquid and gaseous fuels through 2040 and 2050. Across all major pathways, the key finding is that the road transport sector can secure its share of renewable fuels without impacting on the fuel requirements of the aviation or maritime sectors, provided that policy, certification and infrastructure enablers continue to advance. Diversity of fuels is the main strength: each pathway contributes to different vehicle segments, and overlaps in feedstock use are mitigated by complementary scaling of waste-, residue- and electricity-based routes.

- **FAME, HVO, lignocellulosic biomass and waste-based renewable diesel:** FAME and HVO are well established levers for reducing GHG emissions in road transport, and the incorporation of lignocellulosic biomass and waste-based feedstocks can further scale renewable diesel supply, helping to reduce both climate impacts and land-use pressures. It is anticipated that, by 2050, the global potential for FAME, HVO/SAF, renewable diesel and renewable gasoline will be in the range from 70 Mtoe to approximately 200 Mtoe, with the upper value driven by the full availability of lignocellulosic, waste-based and novel oil feedstocks.
- **Renewable methane:** Biomethane and e-methane together can provide ~5.4 Mtoe of fuel in 2040 and 9.6 Mtoe in 2050 for the road transport sector, mostly for use in HDVs running on CNG/LNG. This represents ~10% of HDV fleet demand by 2050, accounting for only 7% of projected EU biomethane output—meaning that road transport demand can grow without competing with power or heating fuel demand. Distinct feedstock streams (manure, residues, waste) and negative GHG balances can, in some cases, contribute further to reducing climate impacts, thereby enhancing the suitability of biomethane as an HDV fuel.
- **Renewable liquid gas (rLPG/rDME):** Although modest in scale at ~1.9 Mtoe in 2040, rising to 3.8 Mtoe in 2050, these fuels are crucial niche enablers for rural, off-grid heating and autogas markets. As by-products of HVO/FT and synthetic LPG production, they demonstrate the importance of co-product integration while delivering high life-cycle GHG savings.
- **Bioethanol:** With supply around 10 Mtoe by 2040 and 13 Mtoe by 2050, ethanol will be able to cover roughly 15–20% of the road fuel pool, mainly in passenger cars. Expansion to E20/E85 blends, and fully renewable E85 (E85+), will secure this pathway.
- **Renewable gasoline from biomass:** The industrial production of 100% renewable gasoline from biomass is a recent achievement, and market deployment is currently in a pilot phase. However, from a feedstock availability and production technologies perspective, scaling up the production would be possible in the coming years if supported by the necessary regulatory framework which will need to promote continued investment in technology and the use of new feedstocks and production processes. It is anticipated that, by 2050, there is potential for up to 137 Mtoe of renewable gasoline and renewable diesel from lignocellulosic and waste-based feedstocks.
- **E-fuels:** The number of new e-fuels projects planned for development is growing rapidly at the global level. Depending on the industrial scale-up, global production has the potential to reach 35–74 billion litres by 2035 and up to 159 billion litres by 2040. While global renewable resource potential is abundant, the key constraints are electrolysis (cost and availability), renewable electricity deployment, CO₂ sourcing, and financing. Unlocking Europe's potential will require an accelerated expansion of renewable capacity, and a stable regulatory environment to support investment.

Conclusion

Taken together, based on the available data alone, these fuels add up to 91 Mtoe in 2040 and 86–140 Mtoe in 2050, matching the projected EU demand for road transport fuels. Importantly, supply is spread across multiple streams, reducing systemic risk. Feedstock overlaps (notably between HVO/SAF) are real but manageable under EU RED rules and with robust monitoring. The WGMM's development of 11 methodologies for tracking the use of eligible fuels in vehicles further ensures that deployment can be transparently accounted for. Moreover, the ability to exploit the co-production of multiple value products resulting from the same industrial process allows production costs to be reduced while also contributing to the reduction of GHG emissions across all transport sectors.

The ongoing diversification of feedstock sources, including the incorporation of new biofeedstocks through the revised RED Annex IX, further enhances resilience and scalability. To realize their potential, it is important that the upcoming certification guidelines on these newly-integrated categories will be clear and predictable, fostering the creation of new value chains that deliver benefits across all the sectors involved. The substantial potential of lignocellulosic residues from forestry and agriculture, dedicated energy crops and biowastes will strength the supply chain towards 2050, while the inclusion of intermediate crops and crops grown on severely degraded lands will further expand this potential.

In conclusion, a portfolio of renewable fuels, each matched to its most effective application, can make a significant contribution to the energy transition in the road transport sector. Continued policy stability, investment in waste/residue collection, and scaling of RFNBOs are the critical enablers for turning this technical potential into a realized, positive climate impact.

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Appendix

Appendix

Biodiesel (FAME) and renewable diesel (HVO)

FAME biodiesel and HVO are both well-established alternatives to fossil-derived diesel fuel. They are compatible with existing vehicles and distribution systems, and are essential for reducing greenhouse gas (GHG) emissions in the current diesel fleet. Both biodiesel (FAME) and renewable diesel (HVO) are expected to remain significant contributors to the fuel pool in 2030 and 2050. In the EU, FAME and HVO are produced from a mix of crop-based and waste-based feedstocks. Rapeseed oil remains the largest crop-derived input, accounting for 34% of the total, the vast majority being used for the production of FAME. Among waste-based sources, used cooking oil (UCO) is the largest contributor at 24%, followed by other residues and wastes. The GHG reduction of FAME and HVO depends on several factors including the feedstock utilized, the related processing phase, and the process energy, but can be up to 90% when waste or residues are used.

Biodiesel (FAME)

FAME is produced via biomass esterification, where fats are broken down and then reacted with methanol to produce a final product that is similar to fossil diesel fuel but with a higher oxygen content. Like conventional diesel, biodiesel must comply with CEN standard EN 14214.³⁵ This ensures a standard quality and performance when FAME is used in diesel engines, whether as pure biodiesel or as a part of a diesel/biodiesel blend, with maximum 7% (v/v) FAME (designated B7) according to standard EN 590,³⁶ and 10% (v/v) FAME (designated B10) specified in standard EN 16734.³⁷

In addition, the European Commission's Fuel Quality Directive (FQD)^[21] provides for both 7% and 10% (v/v) blends (7% being the 'protective grade', i.e. to protect the integrity and operational safety of certain vehicles and machinery, particularly older engines or those not specifically adapted for higher FAME blends). Biodiesel is currently in widespread use in the form of B7 and B10+ blends, with higher concentrations, such as B20, reported in fleets throughout several EU member states. The GHG reduction of FAME depends on several factors including the feedstock utilized, the related processing phase and the process energy, but can be more than 80% when waste or residues are used.

Renewable diesel (HVO)

HVO is a paraffinic renewable diesel produced by hydrotreating fatty acids and lipid feedstocks such as UCO, and other waste residue oils and fats. It can be used in pure form as a fully drop-in fuel, and co-produces renewable LPG,³⁸ naphtha and SAF. Its GHG reduction potential depends on the feedstock, the process energy and hydrogen source, but is generally substantial when waste and residue-based feedstocks are used. The EEA reports that, in 2022, the HVO used in the EU provided, on average, an 89% GHG emissions saving compared to fossil fuel.^[22] HVO production has been expanding steadily, and the resulting paraffinic fuel may be blended with fossil diesel, limited by the blend meeting the minimum density specification in CEN standard EN 590. Depending on the density of the base fuel, the maximum HVO content is typically around 35% (v/v) for temperate climates and up to 65% (v/v) for severe winter grades.

³⁵ European Standard EN 14214: Liquid petroleum products - Fatty acid methyl esters (FAME) for use in diesel engines and heating applications - Requirements and test methods

³⁶ European Standard EN 590: Automotive fuels - Diesel - Requirements and test methods

³⁷ European Standard EN 16734: Automotive fuels - Automotive B10 diesel fuel - Requirements and test methods

³⁸ Liquefied petroleum gas

HVO can also be sold on the market as a neat fuel (100% HVO) in compliance with CEN standard EN 15940.³⁹

Lignocellulosic biomass and waste-based renewable diesel

Beyond HVO, renewable diesel can be produced from lignocellulosic biomass (such as forest and agricultural residues and dedicated energy crops) and biowastes. This is achieved via thermochemical conversion followed by upgrading (i.e. reacting with hydrogen and a suitable catalyst to remove oxygen and other impurities to create a fuel that is chemically similar to fossil diesel). The principal pathways are: gasification with FT synthesis; fast pyrolysis with subsequent upgrading; hydrothermal liquefaction (HTL) with upgrading; and alcohol-to-distillates (ATD).

The resulting fuel can be used neat or blended, meeting the requirements of either EN 590 or EN 15940, and is fully compatible with existing fuel transportation and storage logistics, as well as with diesel engines in passenger, heavy-duty and off-road applications. Depending on feedstock management and logistics, the process energy and its source, and the hydrogen source, this type of fuel has the potential to provide GHG savings of 82–89% relative to the EU's fossil diesel comparator (in RED III) over a typical life cycle. Technology pathways from lignocellulosic biomass are being developed to scale-up HVO production in the coming years.

Bioethanol/bio-based renewable gasoline

Reducing the carbon content of gasoline relies on two complementary factors:

1. The continued use and increased capacity for production of bioethanol.
2. The introduction of renewable hydrocarbon gasoline molecules, often produced as a co-product of HVO, or produced from the ethanol-to-gasoline (ETG), methanol-to-gasoline (MTG) or FT synthesis processes.

Bioethanol fuel blends

Bioethanol is already widely deployed in Europe, blended in grades such as E5⁴⁰ and E10, with E85 available at more than 5,500 stations as of 2025. E20 has been approved as a technical specification at CEN and published in December 2025. However, the FQD currently sets a maximum limit of 10% ethanol in gasoline, which prevents countries in the EU from implementing this grade. A revision of the FQD would be required if this grade is to be used in the EU-27. National standards bodies in Norway, UK and Switzerland can, however, adopt this as a national standard. On average, bioethanol delivers GHG savings of around 81.6% compared with fossil petrol.^[32] Feedstocks used for bioethanol production are primarily European crops such as maize, wheat and sugar beet, as well as starch and sugar residues, with less than 10% of today's bioethanol being produced from RED Annex IX Part A advanced feedstocks.⁴¹ Ethanol's co-products, such as high-protein animal feed and biogenic CO₂ streams, offer additional benefits and synergies with future e-fuel production.

³⁹ European Standard EN 15940: Automotive fuels – Paraffinic diesel fuel from synthesis or hydrotreatment - Requirements and test methods

⁴⁰ E5, E10, E20, E85 = designation for petroleum fuel blends containing up to 5% ethanol (E5), 10% ethanol (E10), 20% ethanol (E20), 85% ethanol (E85)

⁴¹ The EU is working to increase the use of a wider range of feedstock sources as listed in RED III Annex IX, Part A; currently, these sources are used in less than 10% of bioethanol production due to challenges relating to their availability, collection, processing and associated costs.

Future demand for bioethanol is expected to rise as E10 becomes universally available and E20 adoption expands. Capacity could reach 13 million cubic metres by 2035, with E85 representing a major opportunity for use in hybrid and plug-in hybrid fleets. This would ensure a substantial and cost-effective contribution to reducing the carbon content of the gasoline fuel pool. E85 fuel can easily become 100% renewable by replacing the average 25% fossil gasoline with renewable gasoline molecules, such as the bionaphtha or e-naphtha co-products of sustainable aviation fuels production. In California, 100% renewable E85 has already proven its viability in the retail market, where it is used by about one million flex-fuel vehicles.

Renewable gasoline from biomass

Renewable hydrocarbon gasoline produced from biomass via ETG, MTG and FT, among other processes, is a further option. These processes can produce 100% renewable gasoline fuel components, which could be further processed or blended with other renewable fuel components to produce renewable gasoline meeting CEN standard EN 228.⁴² This 100% renewable gasoline fuel would be fully compatible with petrol vehicles and existing fuel transportation and storage logistics systems, and have very low life-cycle GHG intensities. However, their scale will depend on the pace of project deployment because, unlike other fuels, automotive gasoline is difficult to use in applications other than passenger cars, mainly due to its short shelf life. For that reason, the regulatory framework is a key element in promoting the increase in renewable gasoline production capacity, through continued investment in technology and the use of new feedstocks and production processes.

Renewable fuels of non-biological origin (e-fuels)

Renewable fuels of non-biological origin (RFNBOs), commonly referred to as e-fuels, are produced from renewable hydrogen and renewable CO₂. For road transport, these encompass e-diesel, e-gasoline, e-LPG, e-DME⁴³ and e-methane. Their sustainability depends on the use of renewable electricity, additionality requirements,⁴⁴ temporal and geographic correlation, and the supply of CO₂ from biogenic or direct air capture pathways (EU regulations currently require industrial CO₂ streams to be phased out by 2041). RFNBOs can achieve GHG reductions of 70–95% compared with fossil fuels, depending on the source of electricity and CO₂ inputs. They are fully compatible with existing vehicle systems and fuel transportation and storage logistics, making them attractive options for a smooth transition to low-carbon fuels.

RED III sets binding RFNBO targets for the transport sector across EU member states. Based on these targets, and the requirements of FuelEU Maritime⁴⁵ and ReFuelEU Aviation⁴⁶ targets, at least 0.9–1.0 Mtoe of RFNBOs would be required by 2030. Many member states are implementing more ambitious RFNBO quotas; for example, Finland plans to introduce a minimum mandate for RFNBOs of 4% of total transport fuels by 2030, while Spain have suggested 2.5%, Belgium 2%, and France and Germany 1.5%.

⁴² European Standard EN 228: *Automotive fuels – Unleaded petrol – Requirements and test methods*

⁴³ Renewable dimethyl ether

⁴⁴ Requirements for hydrogen producers to use only electricity sourced from new, dedicated renewable sources

⁴⁵ FuelEU Maritime

⁴⁶ ReFuelEU Aviation

Demand is expected to grow significantly after 2030, particularly as regulations support RFNBO production while industrial scaling drives cost reductions. The EU's 2040 climate target Impact Assessment^[7] foresees a demand of liquid and gaseous e-fuels of 40 Mtoe in 2040 (Scenario S3) and 45 Mtoe in 2050.

According to the International Energy Agency, more than 200 e-fuel projects are currently under development around the world,^[58] although most of these are still in the early stages. According to a study undertaken by the eFuel Alliance and Porsche Consulting in 2026^[12] the maximum global supply potential for e-fuels will be 60 Mtoe in 2035 and 43.3–130 Mtoe in 2040. Assuming that the road transport sector accounts for around 80% of the overall fuel demand, the supply of 34.6–104 Mtoe required by this sector by 2040 is deemed to be achievable. E-fuels rely on renewable electricity, water and CO₂, and large-scale production will occur mainly in regions with abundant renewable energy, e.g. in sunny and windy areas. According to Fraunhofer IEE (2021),^[59] around 7,300 Mtoe of electricity-based liquid fuels could be produced outside Europe—far exceeding global transport sector needs—allowing the diversification of supply sources beyond traditional fossil fuel exporters. By harnessing green hydrogen and captured carbon, e-fuels will broaden Europe's renewable fuel options alongside biofuels. In order to unlock this full capacity, it will be necessary to scale renewable electricity generation capacity in tandem with biofuels production, while at the same time considering the increasing need for renewable energy among all sectors.

Renewable liquid gas (rLPG and rDME)

Renewable liquid gas includes renewable propane, butane and dimethyl ether (DME). Renewable LPG (rLPG, also known as bio-LPG) is often produced as a by-product of the HVO and FT processes, while e-LPG is produced from renewable hydrogen and captured CO₂ through a synthetic process. Both are chemically and operationally compatible with existing vehicle autogas technologies. rDME can be produced as a biofuel via gasification of various biomass sources with subsequent synthesis, or as an e-fuel. GHG reductions of more than 80% are achievable for both rLPG and rDME compared with the EU's fossil fuel comparator (in RED III), depending on the feedstock and production pathway. A 2025 report commissioned by Liquid Gas Europe^[42] projects that renewable liquid gas could reach a total production capacity of 8 Mtoe by 2040 and 30 Mtoe by 2050, with about 20% of this volume available for the transport sector. This would reduce reliance on conventional autogas in significant segments of the autogas market where renewable gas offers a cost-effective, scalable low-carbon solution.

Renewable methane (biomethane and e-methane)

Renewable methane, whether biomethane or e-methane, provides another drop-in solution compatible with existing CNG⁴⁷ and LNG⁴⁸ vehicle fleets and infrastructure. Biomethane is produced by upgrading biogas from anaerobic digestion of agricultural residues, manures, biowaste and sewage sludge, or by gasifying lignocellulosic feedstocks followed by methanation.⁴⁹ E-methane is synthesized via the Sabatier process⁵⁰ using renewable hydrogen and CO₂.

⁴⁷ Compressed natural gas

⁴⁸ Liquefied natural gas

⁴⁹ Methanation of lignocellulosic feedstocks refers to biological anaerobic digestion, where microbes convert complex biomass into biogas (a mixture of methane (CH₄) and CO₂) through multistage biochemical pathways.

⁵⁰ The Sabatier process is a specific type of methanation which involves a catalytic thermochemical reaction in which purified CO₂ reacts with H₂ over a metal catalyst at elevated temperature and pressure to produce synthetic methane (e-methane) and water.

Biomethane delivers very low emissions, and in some manure-based cases even negative GHG emissions compared with fossil methane. The use of digestate (a nutrient-rich by-product of the biomethane production process) as a biofertilizer further improves the environmental life-cycle performance, both through the avoidance of emissions associated with synthetic

fertilizer production, and also by returning important organic matter and nutrients to the soil. Europe produced about 4.4 Mtoe of biomethane in 2023, and estimates of technical potential suggest that around 40 Mtoe could be available by 2030, rising to 149 Mtoe by 2050. The road sector currently consumes around 23% of biomethane, mainly in HDVs.

Table A1: The range of properties required by the EN 15940 fuel standard

Property	Unit	Minimum	Maximum	Method
Density @ 15°C	kg/m ³	765	800	EN ISO 12185 EN ISO 3675
Cetane number	-	70		EN ISO 5165
Flash point	°C	>55		EN ISO 2719
Total aromatics content	% (m/m)		1.1	EN ISO 12916
Viscosity @ 40°C	mm ² /s	2	4.5	EN ISO 3104
Sulphur	mg/kg		5	EN ISO 20846 EN ISO 20884
Copper strip corrosion (3h @ 50°C)	indices	Class 1		EN ISO 2160
Carbon residue (10% residue)	% (m/m)		0.3	EN ISO 10370
Ash content	%(m/m)		0.01	EN ISO 6245
Water content	mg/kg		200	EN ISO 12937
Lubricity, wear scar diameter (WSD) at 60°C	µm		400	EN ISO 12156-1
Oxidation stability	g/m ³		25	EN ISO 12205
Total contamination	mg/kg		24	EN 12662
FAME content	% v/v		7	EN 14078
Manganese content	mg/l		2	EN 16576
Electrical conductivity @ 20°C	pS/m	50		EN ISO 6297 ASTM D 2624
Hydrogen sulphide	mg/kg		2	IP 570 Proc. A
Acid number	mg KOH/g		0.5	ASTM D 664 Proc. A
Cetane index	-	40		EN ISO 4264

Table A2: Estimated feedstock availability, collection rates, key constraints and opportunities

Feedstock type	Estimated availability, 2030 (million tonnes)	Collection rate	Key constraints	Opportunities	References
Used cooking oil (UCO)	2–3	~15% (households), ~90% (professional sector)	Low household collection; traceability of imports	Improve household collection; circular economy integration; stricter verification	Panoutsou, C. and Maniatis, K., 2021 (Imperial College Consultants and Concawe) ^[3]
Animal fats (Category 1 & 2)	~1.5–2.5	High (regulated sector)	Strict sustainability and traceability rules	Valorization of waste streams; co-processing; stricter verification	European Commission, 2024 ('DI Fuels' study) ^[11] Panoutsou, C. and Maniatis, K., 2021 (Imperial College Consultants and Concawe) ^[3]
Vegetable oils	22–25	High (agricultural sector)	Concerns related to land use	Development of low-ILUC-risk crops; policy innovation	European Commission, 2019 (ENSPRESO database) ^[2]
Tall oil pitch	~0.3–0.5	Moderate (pulp industry)	Limited to kraft pulp mills; niche availability	Valorization of forestry residues; RED Annex IX, Part A	RED Annex IX, Part A ^[14]
Palm oil mill effluent	< 0.5	Low (EU); moderate (ASEAN region)	Traceability	Waste valorization; RED Annex IX, Part A	RED Annex IX, Part A ^[14]
Crude glycerine	~0.2–0.3	High (internal to biodiesel plants)	Requires purification; limited external supply	Circular use within biodiesel production	RED Annex IX, Part A ^[14] European Commission (online): Union Database for Biofuels ^[60]
Fatty acid distillates	~0.5–1	Moderate (oil refining sector)	Quality variability	Waste valorization	European Commission (online): 'Union Database' for renewable fuels ^[60]
Soapstock and derivatives	~0.3–0.6	Moderate (vegetable oil refining)	Emulsified content; requires acidulation	Valorization of refining by-products	European Commission (online): 'Union Database' for renewable fuels ^[60] RED Annex IX, Part A ^[14]
Brown grease	~0.2–0.4	Low (grease trap recovery)	High impurity levels; intensive pre-treatment	Municipal waste valorization	European Commission (online): 'Union Database' for renewable fuels ^[60] RED Annex IX, Part A ^[14]

Table A3: Availability of fully renewable E85+ fuel for the EU light-duty vehicle fleet in 2030, 2040 and 2050, and potential numbers of compatible vehicles (projections)

Fully renewable E85+ fuel availability (million m³) and potential numbers of compatible vehicle types (millions)	Bioethanol	Bionaphtha + e-naphtha
Engine type = petrol	75% v/v	25% v/v
2030		
Renewable fuels availability*	13 4	
Renewable E85+ fuel availability	17	
Number of compatible PHEVs	38	
Number of compatible PHEVs as a proportion of the LDV fleet	15%	
Number of compatible HEVs	22	
Number of compatible HEVs as a proportion of the LDV fleet	9%	
2040		
Renewable fuels availability*	20 7	
Renewable E85+ fuel availability	27	
Number of compatible PHEVs	59	
Number of compatible PHEVs as a proportion of the LDV fleet	23%	
Number of compatible HEVs	34	
Number of compatible HEVs as a proportion of the LDV fleet	14%	
2050		
Renewable fuels availability*	25 8	
Renewable E85+ fuel availability	33	
Number of compatible PHEVs	73	
Number of compatible PHEVs as a proportion of the LDV fleet	29%	
Number of compatible HEVs	43	
Number of compatible HEVs as a proportion of the LDV fleet	17%	

* European capacities + imports from third countries (via trade agreements)

Assumptions:

Annual mileage per LDV (km/year):	13,000
Total number of light-duty vehicles in Europe (million):	250
Assumed fuel consumption of a PHEV (litres/100 km):	3.5
Assumed fuel consumption of an HEV (litres/100 km):	6

WGMM

Working Group on Monitoring Methodologies (WGMM)

The WGMM is a voluntary platform that brings together stakeholders from across the entire automotive and fuel value chain to monitor and assess the use and development of eligible fuels* in road transport.

Web: <https://wgmm.eu>

Email: office-wgmm@vbcoll.de

* In the context of the WGMM, 'eligible fuels' means all fuels defined by the Renewable Energy Directive (EU) 2018/2001, provided that they meet the sustainability criteria of that Directive and associated delegated acts, where the same amount of CO₂ from biomass, ambient air or recycled carbon sources is bound in the fuel production as is released during combustion in the use phase. Those fuels shall include renewable and/or synthetic fuels, such as biofuel, biogas, biomass fuel, renewable liquid and gaseous transport fuel of non-biological origin, or a recycled carbon fuel.