Policy Paper

Biofuels

Contents

Executive Summary

Biofuels represent an important opportunity for states with significant agricultural land and resources, Romania included. This type of fuels can contribute to emissions reduction for the existing vehicle fleet, with or without retrofitting.

Bioethanol can be admixed to petrol or even substitute it after modifications have been made to an engine. On the other hand, biodiesel is altered to mirror diesel in terms of its properties.

In the US, the Inflation Reduction Act (IRA) allocates$ 9.4 billion to support biofuels, while Brazil aims to increase biodiesel blending mandate to 15% by 2026, up from 10% in 2022.

In Europe, German Exports of biodiesel have significantly increased since 2014, with destination countries including Spain (42,000 tons in 2014), France, Belgium and Sweden.[1] In 2018, Germany covered 8.1% of its entire primary energy consumption with bioenergy from biomass and biogenic waste. According to recent estimates[2], by 2050, more than a quarter of Germany's primary energy demand could be met by domestic biomass, mostly from crops and agricultural residues, including straw and manure. While there are some biofuels projects which are to be implemented in Romania or which have already been implemented, the market also needs a more coherent regulatory framework.

While there are strategies for each sector pertaining to biofuels, the existing regulations are not yet well coordinated with one another and, most often, do not reflect the trends and targets set at the EU level. Therefore, national regulatory framework (e.g. Law No. 237 / 2023 on the integration of hydrogen from renewable and low-carbon sources in the industry and transportation sectors with the targets set at European level) needs to be harmonized with the one adopted and in force at European level (e.g. RED III) – and the part of biofuels, non-biological renewable fuels should be considered.

An important area for Romanian legislators to consider relates to updating biofuels strategies, particularly for the road and aviation transport sectors, in line with EU legislation.

Main objectives which should be pursued constantly refer to:

- Ensuring development of biofuels production
- Achieving targets set at EU level and transposing them into Romanian legislation
- Expanding road infrastructure in a sustainable manner.

As for the aviation industry, it requires both a suitable legislative framework as well as financial support. A key challenge for this sector is that, across various member states, sustainable aviation fuel (SAF) remains approximately 15% more expensive than conventional aviation fuel. Given that cost is a decisive factor in passenger choice, this price gap represents a significant barrier to SAF adoption.[3] **Without adequate policy measures to support the biofuels sector, most bioenergy alternatives remain economically uncompetitive compared to fossil fuels.** Despite several projects launched in Romania, the low level of technological readiness remains a major barrier to new bioenergy technologies such as biomass-based aviation fuels. In this regard, policy-driven support for innovation—through research, development, and funding—has the potential to accelerate commercial viability and market adoption. Another major challenge to implementing biofuels technology is represented by weak supply chains. These are characterised by unstable supply of feedstocks, a shortage of skilled workers and concerns over sustainability risks due to lack of traceability systems. Additionally, a critical risk factor is the reluctance of farmers to engage in perennial crop cultivation due to economic uncertainty. Since perennial crops do not generate annual revenue, many farmers are unwilling to assume the financial risks associated with their production. Currently, there is a clear reluctance among farmers to enter new markets and cultivate alternative crops, as the significance and benefits of sustainable biofuels remain largely underestimated.

1-Germany (etipbioenergy.eu)
2-ETIP_B_Fact sheet_Bioenergy Germany_feb2020.pdf (etipbioenergy.eu)
3-The Future of Hydrogen AIE report, June 2019[4] https://solartechadvisor.com/biofuel-generations/

1. Introduction: Biofuels

1.1. Definition

Biofuels refer to any fuels derived from biomass, including plant material, algae, or animal waste. Given that these feedstocks are widely available in significant quantities, biofuels are classified as a renewable energy source. Biofuels are commonly categorized into different classifications, such as conventional, advanced, first-generation, and second-generation biofuels. **States differentiate various types of biofuels depending on criteria such as feedstock type, technological maturity, energy efficiency, conversion technology and emissions reduction potential.**

The **EU's Renewable Energy Directive (RED) II** defines **advanced biofuels** based on a list of qualifying feedstocks used for their production.

Meanwhile, the World Bioenergy Association (WBA) provides the following classifications:

- First-generation biofuels – liquid biofuels derived from food or food-related feedstocks, such as cereals, starch-rich crops, sugars, and oil crops.

- Second-generation biofuels – liquid biofuels produced from the structural components of plants and trees, such as lignocellulosic biomass.

1.2. Types of biofuels

Liquid biofuels present particular interest in the industrial sector as their use is supported by an extensive, pre-existing iinfrastructure, especially in **transportation**. The most widely produced liquid biofuel is ethanol (ethyl alcohol), derived through the fermentation of starch or sugar.

In Europe, bioethanol is primarily produced from starch-rich cereal crops, concentrated sugar beet juice, and locally grown plants.

According to the WBA, liquid biofuels can be obtained from a wide variety of feedstocks, cereals, sugars, oil crops, residues and waste. Over the past decades, crops with high sugar content—such as sugarcane, sugar beet, and sweet sorghum—have been the predominant feedstocks for global biofuel production. Among these, sugarcane is the most widely used, requiring a tropical climate and being primarily cultivated in Brazil. Similarly, crops with high oil content, such as soybean, oil palm, and rapeseed, are key sources for biofuel production. These three categories represent the most common feedstock for liquid biofuels. With respect to cellulosic biomass, the high availability of cellulosic material makes it a strong potential feedstock alternative, despite logistical collection challenges that need addressing.

Another source for liquid biofuels is waste, including the biodegradable fraction of municipal solid waste (MSW) and industrial waste. Although further research is needed to optimize waste-to-biofuel conversion, this feedstock is increasingly being utilized for the production of various biofuels. Brazil and the US are among the world's largest ethanol producers. In Brazil, ethanol biofuel primarily derived from sugarcane and is commonly used either as pure ethanol (E100) or blended gasoline formulations containing up to 85% ethanol (E85).

First generation biofuels (also known as "conventional biofuels") are derived from food crops, such as corn, sugarcane, sunflower oil, soybeans, starch and sucrose.

The main process used to convert these feedstocks into biofuel is *fermentation.*[4] During this process, enzymes are used to break down carbohydrates in the biomass into sugars. These sugars are then converted into alcohols, such as ethanol or butanol, which can be used as fuel. Fuels like ethanol and biodiesel represent the first generation of biofuel technology.

In addition, these sugars can also be used to produce **biodiesel**, which is obtained from vegetable oils and animal fats. To obtain this type of fuel, triglycerides in biomass are broken down into fatty acids,

4-https://solartechadvisor.com/biofuel-generations/

which are then reacted with methanol. Prior to this chemical reaction, the biomass is first crushed and pressed to extract the oils. This liquid biofuel has become widely accepted in Europe and is used for diesel engines, often blended with petroleum diesel in varying percentages.

Second-generation biofuels are derived from plants that are not used for food production such agricultural waste, woodchips and grass. The main method for converting these feedstocks into biofuels is thermochemical conversion, which involves the application of heat and pressure to break down complex organic materials into usable fuels.

Third-generation biofuels[5] are advanced biofuels obtained from algae, a type of aquatic plant growing in salt or fresh water. These plants require no land or fresh water to grow, which means they have a smaller environmental footprint compared to first- and second-generation biofuels.

The use of algae and cyanobacteria as sources for third-generation biodiesel has significant potential for future development. However, commercial-scale production remains challenging due to technological and economic constraints. Other biofuels include methane gas and biogas, derived from the decomposition of biomass in the absence of oxygen, as well as methanol, butanol and dimethyl ether.

1.2.1. Types of biofuels depending on engine

Ethanol is a renewable fuel that can be produced from various plant-based sources and is commonly used as a blending agent with gasoline to increase octane number while reducing carbon monoxide and other emissions, according to the US Department of Energy. The most common ethanol blend is E10 (containing 10% ethanol), which is approved for use in most conventional gasoline-powered vehicles, with compatibility extending up to E15 (15% ethanol). Most ethanol production relies on plant starches and sugars, particularly corn starch in the United States, where biofuel ethanol is primarily derived from corn kernels. **Biodiesel** is a liquid fuel produced from renewable sources such as vegetable oils and animal fats, mixed with alcohol. Biodiesel is used to power compression-ignition (diesel) engines and can be blended with petroleum diesel in any proportion. Cold weather performance of biodiesel depends on several factors, including the blend ratio, the type of feedstocks used, and the characteristics of the petroleum diesel. Generally, lower-percentage biodiesel blends offer better performance at low temperatures.[6]

Pure vegetable oil (PPO) or simple vegetable oil (SVO) can also be used as biofuels without requiring intermediate modification or processing. However, due to differences in viscosity and combustion properties compared to conventional diesel, these fuels can only be used in modified or retrofitted engines. As a result, they are primarily used in small-scale applications, such as agricultural machinery, private vehicles or municipal vehicle fleets.

Renewable diesel, also known as hydrotreated vegetable oil (HVO), is a high-quality diesel fuel produced through hydrogenation. HVO can be derived from many of the same feedstocks as biodiesel, including vegetable oils and animal fats.

Hydrogenation serves as an alternative to esterification, where instead of reacting with methanol, the feedstock undergoes high-pressure hydrogen treatment in the presence of a catalyst, resulting in the formation of long-chain, straight-chain paraffinic hydrocarbons.

2. Launching biofuels technology

2.1. The biofuels technology (technical features). How it works?

The European biofuels market has emerged in response to the need for greenhouse gas (GHG) emission reductions in the transportation sector.

Biofuels production involves various technological processes, resulting in different fuel types suited

5-https://solartechadvisor.com/biofuel-generations/
6-Alternative Fuels Data Center: Biodiesel Fuel Basics (energy.gov)

to distinct transportation applications. These fuels are particularly important for sectors where electrification remains challenging, such as maritime transport, aviation, and certain categories of road transport.
According to the World Bioenergy Association (WBA), biofuels production is heavily influenced by national policies, with countries implementing diverse strategies to promote their adoption. These measures—critical in shaping the future role of biofuels—include fiscal incentives, blending mandates, volumetric requirements, and GHG reduction targets.

While biofuels play a key role in decarbonizing sectors resistant to electrification, they also remain an essential component of conventional road transport.[7]
The World Economic Forum (WEF) reports that oil consumption is distributed as follows: 65% in transportation, 7% in industry, 5% in buildings, and up to 17% as a feedstock in industries such as petrochemicals and plastics. As a result, transportation is expected to benefit the most from the transition to biofuels.).[8]
In biodiesel production, the esterification process involves reacting feedstock oils with methanol in the presence of a catalyst, producing methyl esters with properties comparable to conventional diesel. This product is commonly referred to as fatty acid methyl ester (FAME) to distinguish it from other renewable diesel alternatives.
Beyond biodiesel, extensive research and development efforts have led to the advancement of a wide range of biomass-derived liquid fuels, further expanding the potential applications of biofuels across multiple industries.
Biomass-derived liquid fuels (BtL) are produced from solid biomass feedstocks, such as wood residues, crop residues from farms and municipal solid waste. Production is a two-step process including gasification followed by synthesis or fast pyrolysis.

In the first stage, the feedstock undergoes gasification a process in which biomass is partially combusted with limited oxygen input to generate syngas—a mixture of carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), methane (CH_4), nitrogen (N_2), and water vapor (H_2O).

Following this stage, syngas is cleaned and conditioned before being catalytically converted into a liquid or gaseous fuel.

Different fuels can be produced using this method, including:

- Synthetic diesel, derived from carbon monoxide and hydrogen in syngas.
- Synthetic kerosene, which serves as a sustainable aviation fuel (SAF) alternative.
- Bio methanol, produced through the catalytic conversion of conditioned syngas. It can also be obtained by hydrogenating carbon monoxide with mixed alcohols.
- Pyrolysis oil (bio-oil), generated by rapidly heating biomass particles in the absence of oxygen, followed by cooling the vapors into a dark brown liquid biofuel.

Refineries can process 100% feedstocks into profitable renewable diesel and sustainable aviation fuel using hydrotreated vegetable oil (HVO) technology.

The terms hydrotreating, hydro processing and hydrogenation encompass a range of catalytic hydrogen reactions. To produce HVO and HEFA, the following reactions are essential:

- Hydrocracking – Breaks fatty acid chains in the glyceride backbone and reduces long fatty acid chains into shorter hydrocarbons. - Converts unsaturated bonds into single-bonded hydrocarbons, enhancing fuel stability.
- Hydrodeoxygenation Removes oxygen in the form of water (H_2O), improving fuel purity. - Decarboxylation – Eliminates oxygen as carbon dioxide (CO_2), optimizing fuel composition.,
- Isomerization Rearranges linear hydrocarbon chains into branched hydrocarbons to enhance the cold flow properties of aviation fuels.

There are several **technological pathways** that refineries can adopt for biofuels production. These are presented in the image below.

7-https://www.worldbioenergy.org/uploads/200707%20Liquid%20Biofuels%20Factsheet.pdf
8-Oil industry - The Net-Zero Industry Tracker | Forumul Economic Mondial (weforum.org)

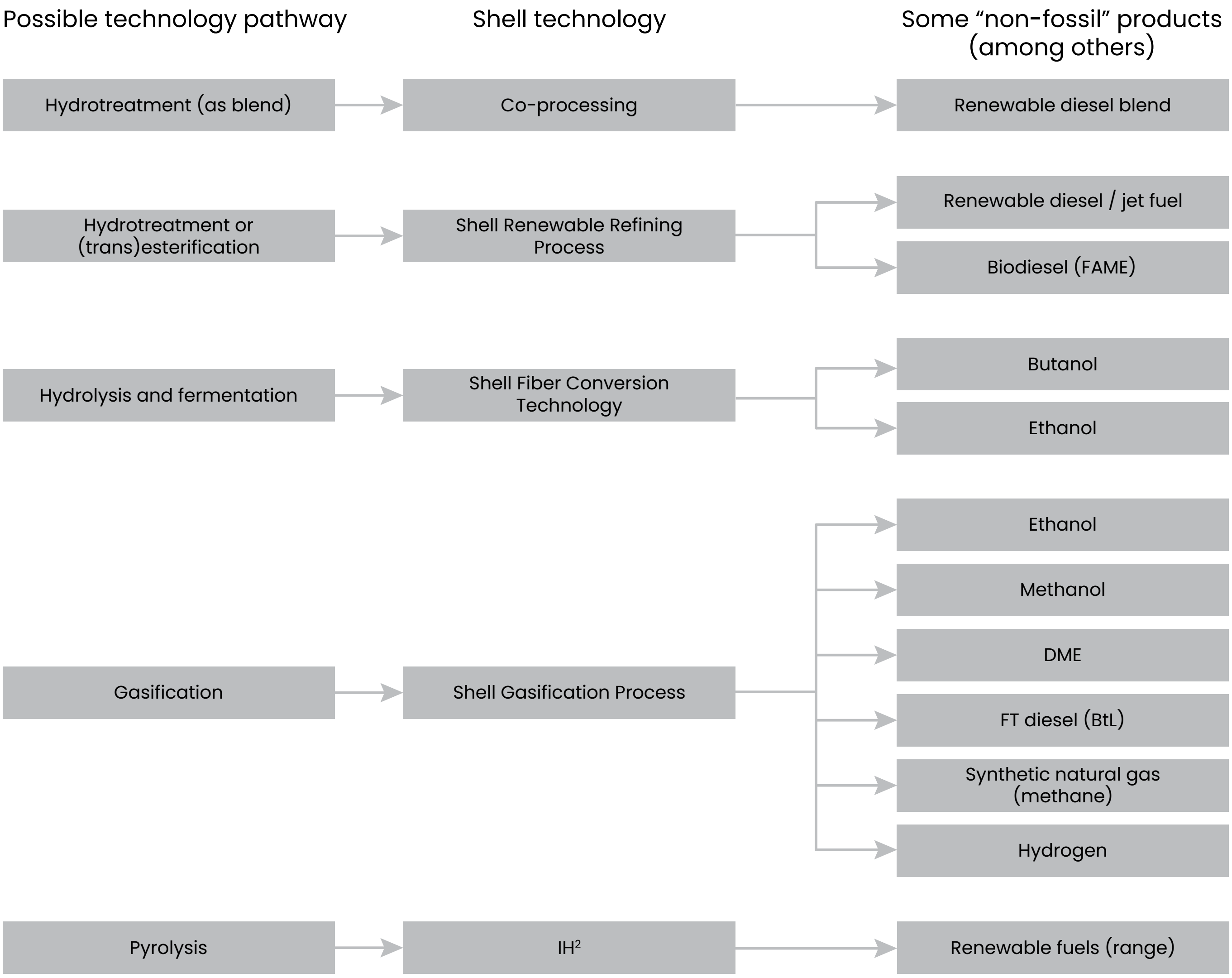
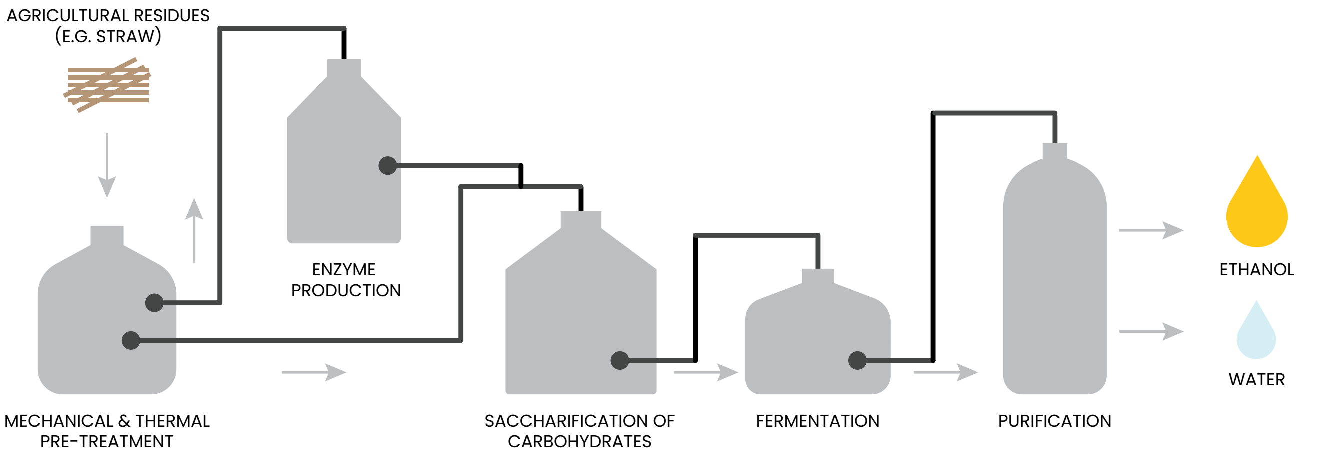


Figure 1: Possible renewable technlogy pathways and the equivalent Shell technologies.

Source: Renewable Fuels Road Map, Shell Catalysts & Technologies – Transforming Energy Together https://catalysts.shell.com/en/investment-benefits-biofuel-technology-white-paper

Various types of feedstocks are converted into cellulosic ethanol through a multi-stage process involving pre-treatment, enzymatic hydrolysis, and fermentation. The integration of enzyme production within the process minimizes overall costs, ensuring greater efficiency and economic viability.

The figure below illustrates the key steps in this conversion process.



Source: Clariant, https://www.clariant.com/en/Business-Units/Catalysts/Sunliquid

The sunliquid® process

Chemical-free pre-treatment reduces both production and capital investment costs while also minimizing environmental, health, and safety risks.

A small percentage of the pre-treated feedstock is utilized for on-site enzyme production at the ethanol plant, ensuring that this process remains an integrated component of the overall production cycle. This approach significantly enhances economic efficiency, leading to substantial reductions in production costs while also ensuring independence from supply shortages and price volatility.[9]

A bespoke enzyme mixture hydrolyses cellulose and heavy cellulose chains to form sugar monomers. This stage is also known as **saccharification.** Enzymes are highly optimised based on feedstock and process parameters, resulting in maximum yields and short reaction times under optimal conditions.

By employing optimised microorganisms, the sunliquid® process enables high-efficiency fermentation, maximizing ethanol yields. At the same time, this optimised system converts both C5 and C6 sugars to ethanol, delivering up to 50% more ethanol than conventional processes which convert only C6 sugars.

The innovative and highly energy saving purification method reduces energy demand by up to 50% compared to conventional distillation. This efficiency is achieved through comprehensive process planning and energy integration.

While hydrolysis and fermentation are typically more suitable for corn ethanol producers, refiners can upgrade corn waste and other fibrous materials to produce second-generation ethanol, which can be leveraged to obtain high-value carbon credits and generate valuable co-products, such as animal protein feed and distillers corn oil, the latter can be used in hydrotreated vegetable oil (HVO) production.

Renewable gases, liquids and, potentially, renewable solids can be gasified into syngas serving as a building block for many products. Additionally, pyrolysis enables the conversion of renewable organic matter and waste into high-value products, further maximizing carbon credits.
For many refiners, the implementation of biofuels technology is likely to start off with co-processing. Pre-treating vegetable oils or meat tallows contribute to reducing the risks of the feedstock blocking the catalyst and reactors. Following this step, the feedstock goes into tanks for blending at up to about 10%. Most refiners already possess the necessary co-processing capabilities.

However, incorporating renewable feedstocks into existing refining operations presents several operational challenges:

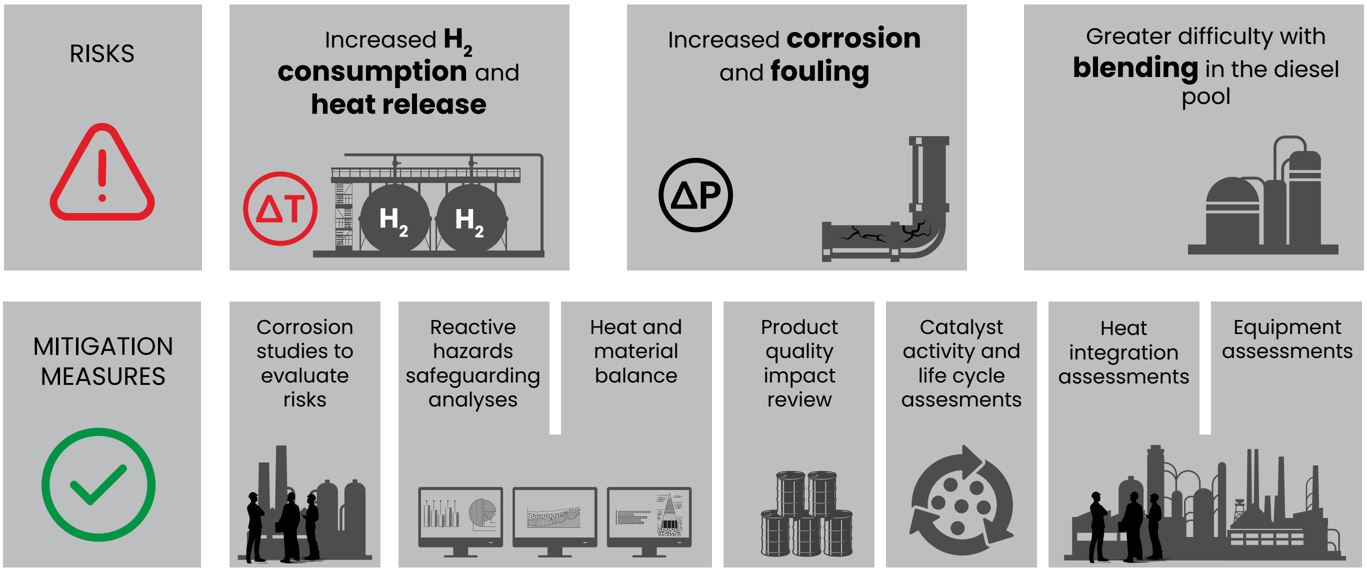
Hydrogen consumption and heat release:

Due to their higher olefin and oxygen content, renewable feedstocks impact hydrogen demand and heat balance within processing units.

- Corrosion and fouling risks: The olefinic and acidic nature of these feedstocks, along with elevated levels of phosphorus and alkaline metals, can contribute to catalyst poisoning, gum formation, and increased corrosion.
- Blending challenges in diesel production: Higher paraffinic content in co-processed biofuels may complicate blending within the diesel pool, requiring adjustments to maintain fuel quality standards.
- To address these challenges, technical service providers leverage tools and techniques adapted from other industrial sectors, effectively managing risks unique to hydroprocessing.

The graph below illustrates the key risks associated with the implementation of biofuels technology.

9-https://www.clariant.com/en/Business-Units/Catalysts/Sunliquid



Many refiners may initially adopt co-processing; however, to align with increasingly stringent renewable targets, they might consider developing dedicated units capable of processing 100% renewable feedstocks. Under RED II—and its current revision, RED III—European refiners are mandated to incorporate larger volumes of more challenging feedstocks, such as algae, straw, and specific biowastes. Existing HVO units are not equipped to process these types of feedstocks.

As a result, many oil and gas companies currently seek to expand the range of feed stocks they can process.

Lanza Tech Technology

US biotech company Lanza Tech has developed a breakthrough technology that converts waste carbon into sustainable fuels, fabrics, and packaging materials used in everyday life. According to the company, it has recently achieved a major milestone by creating specialized biocatalysts capable of directly producing ethylene from CO_2 in a continuous process.

Ethylene is the most widely used petrochemical globally, with an annual production volume of approximately 160 million tons. Traditionally, ethylene is produced from fossil feedstocks through an energy-intensive process that emits significant amounts of CO_2. This new innovation offers a low-temperature, energy-efficient alternative that can reduce carbon emissions by converting CO_2 into a valuable feedstock for ethylene production. The ethylene production process is considered one of the largest sources of CO_2 emissions in the chemical industry and remains a major challenge for decarbonization.

In addition, Lanza Tech has launched CirculAir™, an innovative technology that converts waste, carbon, and renewable energy into sustainable aviation fuel (SAF), offering a more cost-effective alternative to Fischer-Tropsch technology. This method enables the production of SAF from a wide range of waste sources, including:

- Municipal solid waste (MSW)
- Agricultural residues
- Industrial carbon emissions
- CO_2 captured directly from the atmosphere
- Renewable energy sources

Using a novel gas fermentation technique, this process transforms waste-based carbon sources into ethanol, which is then converted into drop-in SAF. This approach enables large-scale production of SAF, leveraging a diverse range of waste materials.

SAF is projected to account for 65-70% of the total emissions reduction needed for the aviation industry to reach net-zero by 2050. However, long-standing supply limitations, high production costs, and technical barriers have hindered the widespread adoption of SAF as a primary aviation fuel.

According to LanzaTech, SAF produced using this method is expected to reduce aviation emissions by at least 85%, providing a viable pathway for decarbonizing air travel.

2.2. Key benefits of biofuels technology

Biofuels play a crucial role in decarbonising transport by providing a low-carbon alternative for existing technologies, such as light-duty vehicles in the near term and heavy-duty vehicles, trucks, ships and aircraft with few alternatives and cost-effective solutions in the long term.[10]

A key advantage of first-generation biofuels is that they have high energy yields.[11] However, their production competes with food crops for land and water, raising concerns about their environmental impact.

By contrast, second-generation biofuels offer several advantages, primarily because they do not compete with food crops for essential resources like land and water. This makes them a more sustainable option compared to first-generation biofuels. Additionally, second-generation biofuels can be produced from a diverse range of feedstocks, increasing their availability and scalability. However, a significant challenge is that the conversion processes for second-generation biofuels are less developed and less efficient, resulting in lower energy yields compared to their first-generation counterparts.

Many HVO (hydrotreated vegetable oil) processes are single-stage, but a two-stage processing unit offers significant advantages. This method results in higher yields of diesel and jet fuel, as the clean second-stage environment allows for high-severity isomerization. This step is essential for achieving low cloud points for winter diesel and lower freezing points for sustainable jet fuel, all while minimizing cracking.

Determining factors for investment in biofuel production capacity depend both on the location of the refinery and the markets it serves.

Liquid biofuels are a technically and economically feasible alternative to petroleum-derived fuels. A major advantage is the possibility to produce these fuels locally, which can help support national energy security while simultaneously providing jobs and income resources for farmers and facilitating overall economic development. The IEA Technology Roadmap, for example, found that, in order to have a 50% chance of limiting global warming to 2°C, the contribution of bioenergy in the transport sector will need to increase tenfold from 2015 levels by 2060.

Biofuels can be produced from a wide range of organic materials through various technological production pathways, each resulting in fuels with distinct properties. The high market value of biofuels means that producers can expand beyond minimum compliance requirements to develop economies of scale for feedstock logistics, including transportation, storage, and pre-treatment. [12]

HVO (hydrotreated vegetable oils) offer several advantages, including high cetane number, high energy density, long-term storage stability, clean combustion, and reliable performance at low temperatures. Additionally, HVO is a drop-in fuel, meaning it can be used in existing fuel infrastructure without modifications. It can also be converted into drop-in renewable kerosene for jet fuel applications.

HVO is primarily used as renewable diesel for road transport, whereas HEFA (Hydroprocessed Esters and Fatty Acids) is designated for sustainable aviation fuel (SAF). Both processes rely on esters and fatty acids as feedstocks, and the terms hydrotreating and hydroprocessing are often used interchangeably to describe their production.

10-Biofuels - Energy System - IEA
11-Biocombustibili de prima, a doua, a treia generație: Care este diferența?" | Solartechadvisor
12-https://catalysts.shell.com/hubfs/Renewable%20fuels%20road%20map%20%7C%20Shell%20Catalysts%20&%20Technologies.pdf?hsCtaTracking=1dd0d926-9cf7-48b4-98fc-4bd20a1da3ae%7C64f5d50a-08f0-4feb-9edd-86d118bfa5c6

Despite similarities in production, there are key differences between HVO and HEFA. Aviation fuels require shorter hydrocarbon chains, meaning the process involves additional cracking, which can lead to higher co-product yields. Furthermore, aviation fuels undergo an additional isomerization step to improve cold flow characteristics. While isomerization is not required for HVO (on-road diesel), some producers still apply it to enhance product quality.

2.3. Contribution to fighting climate change

The transportation sector accounts for nearly a quarter of global energy-related carbon dioxide emissions, while in 2021, nearly 93% of the energy used in the road transport and railway sector in the EU came from fossil fuels.[13]

Given this context, identifying a feasible solution that benefits both Member States and the EU, as well as for emerging industries, is critical to decarbonising the transportation sector and to achieving the agreed climate targets. Biomass-based alternative fuels provide a low-carbon transport alternative while offering a sustainable pathway to reducing oil dependence. The challenge of greenhouse gas (GHC) emissions and climate change has become increasingly significant with respect to fossil fuel consumption in the transport sector.

Since **the transport sector accounts for nearly a quarter of global energy-related CO_2 emissions,** decarbonising this sector becomes necessary to cutting down emissions.

To address this issue, The European Commission introduced the Renewable Energy Directive (RED) (2009/28/EC), establishing a comprehensive policy framework for the production and promotion of energy from renewable sources in the EU. The revised Renewable Energy Directive (RED II) (2018/2001/EU) further reinforced the role of biodiesel as a key contributor to EU climate and energy goals. This directive supports the EU's commitment to reducing emissions under the Paris Agreement, while ensuring the Union remains a global leader in the renewable energy sector.[14]

Under the latter Agreement, dating from 2015, the EU committed to reducing greenhouse gas emissions by at least 40% below 1990 levels by 2030. However, in 2021, the EU adopted the European Climate Act raising its climate ambition by setting a legally binding target to cut emissions by at least 55% by 2030 (compared to 1990 levels), and placing Europe on a trajectory towards climate neutrality by 2050.

Transport policy and legislation should be guided by comprehensive data on vehicle life cycle greenhouse gas (GHG) emissions to ensure that regulatory measures do not inadvertently lead to an overall increase in emissions. Incorporating a life cycle approach provides additional benefits, particularly by integrating total cost of ownership and carbon abatement costs, allowing for more effective and cost-efficient decarbonization strategies.

To achieve meaningful reductions, life cycle emissions data should be systematically embedded into future government policies, ensuring that transport decarbonization efforts account for the full environmental impact of different fuel and vehicle technologies.[15]

Furthermore, organisations developing their **fleet decarbonisation strategies** should consider vehicle life cycle emissions, rather than just tailpipe emissions. Both low carbon fuels and zero (tailpipe) emission technologies should be considered before investing in new vehicles, to ensure the feasibility of the business models.

At the same time, low carbon fuels may also provide a faster pathway to reducing fleet GHG emissions in the near term. Feedstocks and resources, for both low carbon fuels and electric vehicle batteries, should be allocated to maximise the overall GHG emissions abatement.

In other words, governmental policies should consider and monitor competing demands, as well as available decarbonisation solutions across key economy sectors. The supply and employment of low carbon renewable fuels should be maximised, particularly in areas that are more challenging to electrify in short to medium term, such as long-haul HGVs.[16]

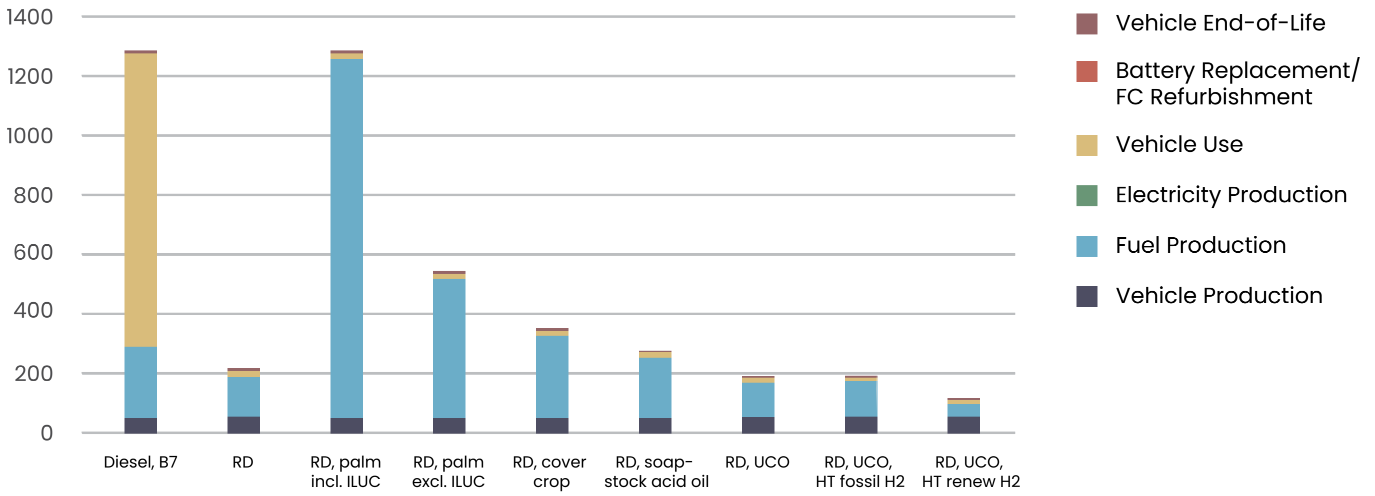
13-EU Court of Auditors Special Report - EU support for sustainable biofuels for transport - A blurred path.
14-https://www.ewaba.eu/resources
15-https://www.zemo.org.uk/assets/reports/Vehicle%20life%20cycle%20GHG%20emissions%20study%202024.pdf,January 2024
16-https://www.zemo.org.uk/assets/reports/Vehicle%20life%20cycle%20GHG%20emissions%20study%202024.pdf

In the short to medium term, renewable fuels could have an essential contribution to GHG emissions reduction. To achieve this goal, **renewable fuels need to meet the affordability and availability criteria.** In addition, companies purchasing renewable fuels in significant quantities should consider the high sensitivity of vehicle life cycle GHG emissions to the fuel supply pathway, as well as monitor the information provided to them by potential suppliers.[17]

Biofuels and renewables are key to achieving the mobility requirements of the 21st century while keeping CO_2 emissions down. According to Zemo Partnership[18], combining renewable fuels with hybrid vehicles could provide an effective decarbonization solution for applications where fully electric vehicles remain economically unviable, due to factors such as power demand, vehicle range, or recharging infrastructure constraints.

The graph below shows the impact of renewable diesel feedstock on vehicle life cycle GHG emissions. According to the graph, it is worth noting that in cases where renewable diesel is produced using palm oil and the indirect land use change factor is included, the renewable diesel offers no significant GHG savings compared to pump diesel.

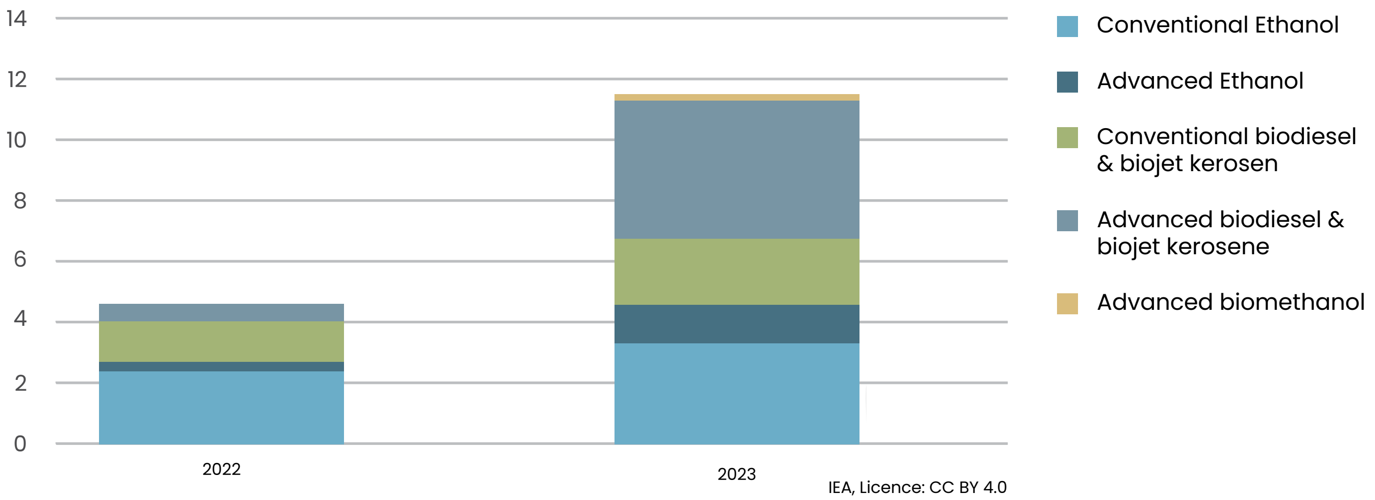
Renewable diesel feedstocks



Source:

https://www.zemo.org.uk/assets/reports/Vehicle%20life%20cycle%20GHG%20emissions%20study%202024.pdf

Liquid biofuel production by feedstock & technology in the Net Zero Scenario, 2022 & 2030



Source: IEA, Biofuels - Energy System - IEA

17-https://www.ewaba.eu/resources
18-https://www.zemo.org.uk/assets/reports/Vehicle%20life%20cycle%20GHG%20emissions%20study%202024.pdf

2.4 Examples of pilot projects successfully implemented at European and international level

Pannonia ethanol facility (Hungary)

Hungary's Pannonia ethanol facility is the largest ethanol production unit in Europe, processing nearly 1.1 million tonnes of corn annualy into 400,000 tonnes of ethanol (500 million liters), 325,000 tonnes of various high protein/ high fat animal feeds and 12,000 tonnes of corn oil.

Pannonia Bio operates a multi-product biorefinery, using state-of-the-art production processes. In the refinery, **corn kernels are broken down into their constituent parts, namely starch, protein, oils and fibre, all these elements having the potential to result in energy, nutrition, health and biochemical products.**

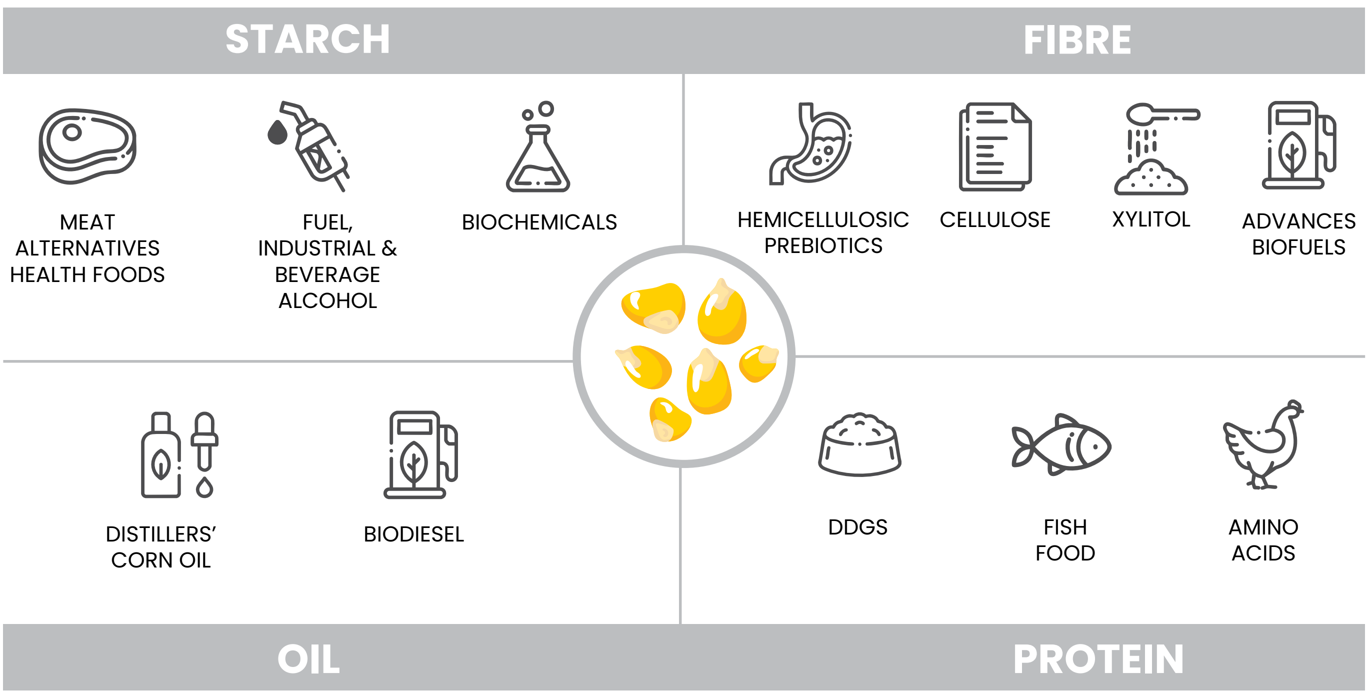
New starchand fibre-based bioproducts are currently in trial production at the Hungarian refinery. These have major development potential for applications in high value-added areas.

The production process begins with starch conversion into simpler sugars in the liquefaction system. The fermentation process then converts sugar into alcohol, forming a beer containing nearly 15% ethanol. This is distilled into 95% pure ethanol in the distillery section, and dehydration further purifies it to 99.8%, yielding over 500 million liters of bioethanol annually.[19]

Removing starch increases the nutrient value of corn. Each kernel originally consists of 70% starch, 9% protein, 4% fat, and 10% fiber. After processing, the final nutrient composition reaches 35% protein, 9% fat, and 4% fiber, with starch reduced to just 3%.

The facility produces hundreds of thousands of tonnes of protein-rich animal feed per year. Further biorefinery developments are expanding the range of protein products for both human and animal nutrition, including applications in fish feed and amino acids. The plant also utilizes corn oil to produce liquid animal feed and over 10,000 tonnes of distillers' corn oil annually.

BIOREFINERIES CAN TRANSFORM CORN KERNELS INTO THESE MATERIALS



Source: https://pannoniabio.com/products/bioproducts

19-https://pannoniabio.com/products/bioproducts

The hard fibre from corn is used to develop renewable biochemical products, as part of a mix with other elements of corn, including oligosaccharide prebiotics, xylitol (sugar alcohol) and cellulose.

Ethanol from the Hungarian biorefinery is primarily marketed as a climate-friendly alternative to petrol, reducing CO_2 emissions by nearly 80% compared to fossil fuels. This ethanol is compatible with both vehicles and the existing fuel distribution system.

As a fuel, ethanol enables engines to run more efficiently and with lower emissions, reducing exhaust pollutants and aromatics. Ethanol not used in the transport sector is directed to the chemical, cosmetics, and beverage industries.

According to the Pannonia Bio, "there is tremendous potential for use in the future [...] in the biobased material sectors, for packaging, coatings and film applications".[20]

Agrana's bioethanol plant (Austria)

Agrana's bioethanol plant in Pischelsdorf, Austria, converts nearly 620,000 feedstock tonnes to 190,000 tonnes of ethanol. Bioethanol is derived from the fermentation of carbohydrate-rich biomass, such as sugar and starch, and contains at least 99% alcohol by volume, making it virtually water-free. The plant has been operational since 2008 and remains Austria's only bioethanol production facility. Its strategic location was chosen based on proximity to feedstock sources, transport infrastructure (Danube access, roads, and railways), and optimized energy supply options.[21]

Each year, the plant produces approximately 250,000m³, a volume sufficient to meet Austria's domestic demand in the event of an E10 fuel mandate. Currently, AGRANA exports nearly half of its bioethanol production, meaning Austria forgoes potential CO_2 savings while having to purchase costly emissions rights on the global market. According to the company, the introduction of E10 in Austria would not require additional production capacity or land, as reduced exports would be sufficient to meet domestic demand. The Pischelsdorf biorefinery originally focused on producing wheat starch and wheat protein. By-products, including bioethanol and GMO-free, protein-rich animal feed, are processed in the adjacent bioethanol plant from unused feedstock components. Additionally, gluten, used in bakery production, and biogenic CO_2, supplied to the beverage industry, are among the other key co-products of the facility. Regarding biodiesel production, the Austrian plant blends biodiesel with conventional diesel in accordance with legal admixture requirements. The facility also supplies 100% biodiesel, which is available at fueling stations across Austria.

Bioro Biodiesel Refinery (Belgium)

The Bioro biodiesel plant in Ghent, Belgium, is one of the few industrial complexes in Europe with the capacity to provide complete end-to-end biodiesel production in a single integrated site. The facility comprises a multi-seed crushing plant and a semi-refinery for vegetable oils, enabling complete feedstock processing into a finished product that is then distributed to customers.

Using state-of-the-art JJ Lurgi technology, the plant has the capacity to produce up to 400,000 metric tons per year of fatty acid methyl esters (FAME) - a biodiesel derived from renewable sources, which can supplement or replace mineral diesel in applications such as off-road vehicles and stationary engines.[22]

This technology exceeds the EN 14214 specifications, the European standard outlining the quality and testing requirements for FAME-based biodiesel. The plant began biodiesel production in April 2008, primarily using vegetable oils as feedstock.

20-https://pannoniabio.com/products/bioethanol/
21-https://www.agrana.com/en/products/all-productportfolios/bioethanol/production-sites
22-Rafinăria Bioro Biodiesel | Cargill

3. Opportunities for introducing biofuels in Romania

3.1. Romania's potential

Romania is the largest country in Southeastern Europe, with vast plains in the Western and Southern regions. Nearly half of its territory is covered by natural and semi-natural ecosystems. Moreover, it is also the largest energy market in the region, with an estimated total final energy consumption of about 25,000 ktoe in 2020.[23]

Romania has significant biomass potential, with several ongoing projects. Biomass ranks as the third-largest contributor in the energy mix, accounting for around 4Mtoe, primarly used in biogas production, CHP and heating.

Given the size of its agricultural sector, Romania generates substantial quantities of agricultural waste that remain underutilized. By leveraging this resource and implementing supportive public policies that facilitate private investment and access to EU subsidies (e.g., Modernisation Fund), Romania has the potential to become a leading biogas producer in Europe. So far, Romania has increased **mandatory blending targets**, reaching 8% for petrol and 6.5% for biodiesel in 2020. Romania has installed capacities to produce biodiesel and conventional ethanol, with an advanced bio refinery being built in the south part of the country.

However, it is crucial to highlight that, undeniably, biofuel production depends on the existing policies and regulatory framework at the national and European level.

In recent years, Romania has expanded liquid biofuel production, particularly conventional biodiesel. In 2007, approximately 430,000 hectares were cultivated with rapeseed. The country's installed biofuels production capacity is estimated at 295 ktoe, comprising 206 ktoe of biodiesel and 89 ktoe of bioethanol. Annual consumption reached 167 ktoe, while domestic production remains limited to around 105 ktoe, requiring imports of an additional 62 ktoe. Production and consumption levels have fluctuated in recent years.

Romania's potential for biofuels production is based on two components:

- 1. **Major agricultural production**, as Romania ranks among top sunflower growers.
- 2. **Used tyres available at national level**, which can be turned into biofuel through pyrolysis.

From a refiner's perspective, **biofuel trading is a rather complex process as markets are different for biofuels than those for trading fossil fuels.**

Legislative frameworks also vary significantly across regions. Within Europe, member states implement the RED II and RED III Directives differently, while in the United States, regulatory provisions are often conflicting. This results in inconsistent product valuation across countries, with no uniform, transparent framework governing both legislation and feedstock classification.[24]

3.2. Romania's technological potential

In recent years, Romania has expanded liquid biofuel production, primarily through biogas, conventional biofuels, and biodiesel, with installed capacities of approximately 80 Mt per year. In addition to existing conventional biofuel production, Clariant constructed a commercial-scale plant in Podari, near Craiova, utilizing sunliquid® technology to produce cellulosic ethanol from agricultural residues, with an annual capacity of 50,000 tons.

However, in December 2023, Clariant announced it had shut down its sunliquid® bioethanol production at Podari, alongside the downsizing of Biofuels and Derivatives business line in Germany.

After developing the sunliquid® technology, the company had decided to establish its own commercial sunliquid® plant in Romania, where bioethanol production began in 2022.

23-https://www.etipbioenergy.eu/images/ETIP_B_Fact%20sheet_ROMANIA_new_feb2020.pdf
24-https://catalysts.shell.com/hubfs/Renewable%20fuels%20road%20map%20%7C%20Shell%20Catalysts%20&%20Technologies.pdf?hsCtaTracking=1dd0d926-9cf7-48b4-98fc-4bd20a1da3ae%7C64f5d50a-08f0-4feb-9edd-86d118bfa5c6

By July 2023, Clariant launched a strategic assessment of its plant operations , concluding that the plant had failed to meet its operational targets. Management ultimately determined that, given the ongoing financial losses, further ramp-up would require significant additional capital expenditure, which could no longer be justified.[25]

As part of its preliminary financial assessment, Clariant estimated closure-related cash impacts of approximately CHF 110–140 million in 2024, with additional costs of CHF 10–15 million linked to maintaining technology licensing capabilities.

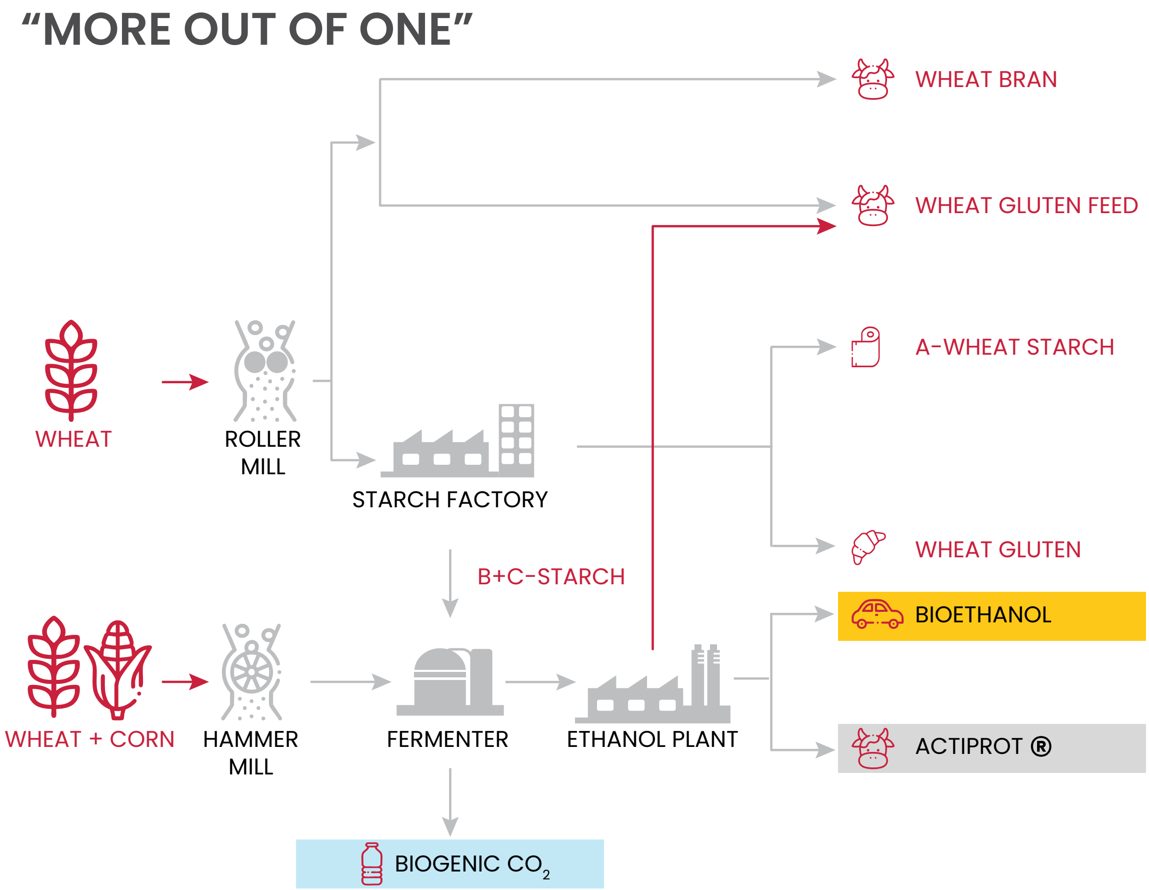
Meanwhile, Alfa Laval provides prefabricated biodiesel plant equipments in Romania, offering standardized solutions for small-scale biodiesel production as well as customized industrial-scale solutions. These systems are specifically designed to optimize biodiesel production efficiency. [26]

3.3. Areas of interest for the implementation of biofuels technology

Bioethanol can be used either as pure fuel or as an admixture to conventional petrol. Its production follows a dual-purpose approach: starch-rich plant components are processed into ethanol, while protein-rich fractions are utilized for high-value animal feed.

During bioethanol production, plants absorb CO_2 as they grow, converting it into starch or sugar, which is then stored within the biomass. At bioethanol facilities, these plant-based sugars undergo fermentation and processing, transforming them into alcohol. The full production cycle, from feedstock intake to the final bioethanol product, takes several days.

The detailed production steps are illustrated below.



25-Clariant shuts its sunliquid® bioethanol plant in Romania
26-Producţie biodiesel | Alfa Laval https://www.agrana.com/en/products/all-productportfolios/bioethanol/products-and-by-products

A by-product resulting from bioethanol production at AGRANA's bioethanol plant is AcriProt®, a premium animal feed produced mainly from wheat and corn.[27] The solid components left over from the production of ethanol, the so-called stillage, are dried and mixed with the residual liquids which are thickened to the consistency of a syrup. This is then dried and pelleted to produce animal feed. AcriProt® is a high-end animal feed produced from locally grown materials.

During bioethanol production, biogenic CO_2 stored in plants is released. This CO_2 is captured and supplied to industrial gas companies, such as AIR LIQUIDE, with approximately 100,000 tonnes made available annually for applications such as carbonated beverage production. This process ensures full material utilization while significantly reducing fossil-based CO_2 emissions.[28]

Biofuels are increasingly being used for transportation, power generation, and heating applications, while minimising environmental impact.

Beyond energy applications, bioethanol plays a key role in the pharmaceutical industry, where it serves as an excipient and solvent in drug formulation. It also functions as a carrier for active ingredients, enhancing dissolution and drug delivery. The growing focus on solubility enhancement and advanced drug delivery systems has led to increased demand for bioethanol in pharmaceutical applications.

The pharmaceutical sector's reliance on bioethanol is driven by several factors:

- **Regulatory compliance: Bioethanol meets strict safety and quality standards for pharmaceutical use.**

- **Safety assurance: Its use aligns with pharmaceutical regulatory guidelines.**

- **Solubility enhancement: Bioethanol improves the dissolution of active pharmaceutical ingredients, particularly hydrophobic drugs, enhancing absorption and therapeutic efficacy.[29]**

In many countries, starch feedstocks ensure a stable and reliable bioethanol supply, leading to the dominance of starch-based bioethanol in the market. Additionally, existing infrastructure - including ethanol plants, transportation networks, and blending facilities - supports the continued production and distribution of starch-based bioethanol.

4. The need for implementing biofuels technology in Romania

Biofuels demand reached a record high of 170,000 million liters[30] , surpassing pre-pandemic 2019 levels.

According to Romania's National Strategy 2030, the use of heat pumps is expected to increase significantly by 2035 contributing to centralized energy demand. The strategy also anticipates an increased role for biofuels and green gas. To support this transition, it promotes the installation of pellet stoves and other biofuel-based heating solutions, which offer higher thermal efficiency and lower emissions compared to wood burning. Between 2018 and 2022, Romania increased its reliance on biodiesel imports, which reached 55% in 2022 to meet rising domestic demand. The energy potential of biomass is estimated at 318,000 TJ per year, equivalent to 7.6 million tons of oil equivalent (Mtoe).

By 2022, renewable energy and biofuels accounted for 12% of Romania's primary energy mix, while coal contributed 14%, oil and oil products 36%, and natural gas 30%. Programmes such as the National Plan for Recovery and Resilience (PNRR) play a crucial role in meeting EU climate targets, directing over €13 billion in investments toward green energy development, including biofuels..

The Government Emergency Ordinance (GEO) No. 80/2018 was amended including the **obligation to market only gasoline and diesel blended with biofuels**, and the part concerning the importer, the place of distribution of fuels, the producer and the operator of the place of distribution. According to the Ordinance, as of January 1, 2019, fuel suppliers are obliged to sell to final consumers only gasoline containing at least 8% biofuels by volume.

27-https://www.agrana.com/en/products/all-productportfolios/bioethanol/products-and-by-products
28-https://www.agrana.com/en/products/all-productportfolios/bioethanol/products-and-by-products
29-https://www.marketsandmarkets.com/Market-Reports/bioethanol-market-131222570.html?gad_source=1&gclid=EAIaIQobChMIz5iDz6C9hgMVNbxoCR0Gvg4SEAAYAiAAEgJyvfD_BwE.30-Biofuels - Energy System - IEA
30-Biofuels - Energy System - IEA

Additionally, according to this Ordinance, in cases where, as part of the applicable product standard, the ethanol present in gasoline exceeds 5% by volume or the oxygen content in gasoline exceeds 2.7% m/m, the label must include a warning message to the end customer, the ultimate intended purpose being to verify the compatibility of the engine with the type of fuel used.

According to the International Energy Agency (IEA), the use of advanced biofuel feedstocks must expand to meet climate targets. By 2030, biofuels derived from waste, residues, and non-food energy crops are expected to represent over 40% of total biofuel demand. Romania has increased liquid biofuel production in recent years, particularly in biogas, conventional biofuels, and biodiesel, with installed capacities reaching approximately 80 Mt per year. The electrification of heavy-duty vehicles is still in its early stages. During this transition, renewable fuels can serve as an intermediate solution while the market for zero-tailpipe emission heavy-duty vehicles develops.

Additionally, for electric vehicles, battery-related factors - including feedstock sourcing, production, life cycle, and replacement frequency - significantly influence lifetime GHG emissions.

According to the IEA, RES-T (Renewable Energy in Transport) amounts to 5%, while Eurobserv'ER reports that Romania is fully compliant with current targets, with bioethanol consumption of 91.1 ktoe and biodiesel consumption of 206.2 ktoe.[31]

5. Opportunities to update the current legislative framework

5.1. Missing elements in the current legislative framework

Once the renewable energies directive (RED) came into force in 2009, the EU established mandatory blending rates for renewable energy transport, which have since been reviewed under the revised RED II and RED III.

With reference to the current time, the share of renewable energy consumption in the transport sector should be at least 29% (with multipliers).

Biofuels used to meet the EU emissions targets must comply with strict sustainability criteria, ensuring that feedstock sourcing, cultivation, and production deliver greenhouse gas (GHG) reductions compared to fossil fuels. This compliance is verified through certification based on the ISCC standard. To meet the sustainability criteria, set by the standard, biofuels must achieve greenhouse gas reductions throughout their life cycle equivalent to at least 35% by the end of 2016 and at least 50% when compared to fossil fuels in order to qualify as biofuels.

We propose the re-evaluation of volumes estimated in Romania's 2030 Energy Strategy regarding biofuels and synthetic fuels, as it currently estimates insufficient quantities, diverging from EU regulations. This revision is necessary to align national legislation with EU regulations while setting realistic targets.

Furthermore, it is essential to harmonize the national regulatory framework (e.g., Law No. 237/2023 on the integration of renewable and low-carbon hydrogen in industry and transport) with the EU's RED III, incorporating biofuels, non-biological renewable fuels, and related segments.

There are also specific feedstock sustainability requirements for bioethanol production, including:

- feedstocks must not be sourced from areas with a high degree of biodiversity (ie rainforests and moors).
- fertilisers and pesticides may only be used to a limited extent.
- end-to-end traceability must be insured with respect to the origin of feedstocks used.

Most importantly, financial support from the Romanian state is needed to develop the biofuels' market at the national level.
At the same time, **public awareness** is also needed to shape up a full picture of the important part that biofuels will have, and the benefits associated with them.

31-ETIP_B_Fact sheet_ROMANIA_new_feb2020.pdf (etipbioenergy.eu)

Currently, the Ministry of Energy is involved in the development of this sector, exploring biofuel expansion through subsidies. An inter-ministerial committee has been established to develop an alternative fuel market.
Currently, there are two financing instruments: the National Resilience and Recovery Plan and the Modernisation Fund.

Another area requiring government action is the development of a clear, transparent regulation for investments in alternative fuel infrastructure.
It is worth noting that Romania currently lacks a transport strategy for the next 15 to 20 years. An inter-ministerial committee dedicated to mobility is expected to be established at the Chancellery level. In terms of the automotive sector's weight, it accounts for 11% of GDP and 20% of Romanian exports. This sector needs further support to develop, including through the development of biofuels.

Additionally, on a technical level, more pilot projects are needed to validate the technology at the national level.

Romania's National Integrated Energy and Climate Plan states in its Policies chapter the need to develop an advanced biofuels market.

The plan indicates the Law establishing the system for promoting energy production from renewable energy sources as a legislative framework for attracting investments. The provisions of this law set out rules on guarantees of origin, applicable administrative procedures and grid connection for renewable energy and establish sustainability criteria for biofuels and bioliquids. In addition, the law introduces a system for the promotion of renewable electricity.

The Integrated Plan also mentions *Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on a level playing field for sustainable air transport (ReFuelEU in aviation).* According to the latter:

- Suppliers of aviation fuel shall ensure that all aviation fuel made available to aircraft operators at each airport in the Union contains the minimum SAF quotas, including the minimum synthetic aviation fuel quotas: from 1 January 2025 (as a starting year), each year a minimum quota of 2% of SAF, while from 1 January 2050, each year a minimum quota of 70% of SAF.

- EU airport managers shall take all necessary measures to facilitate access by aircraft operators to aviation fuels containing the minimum SAF quotas.

- Aircraft operators will not claim benefits for the use of an identical batch of SAFs in more than one greenhouse gas scheme. Aircraft operators shall not claim benefits for the use of the same batch of SAFs in more than one greenhouse gas reduction scheme.

- Union airport operators, aviation fuel suppliers and fuel handling service providers shall cooperate with their member states to prepare national policy frameworks for the installation of alternative fuel infrastructure.

5.2. Recommendations for updating the current legislation to reflect the requirements of biofuels technology

An important area for Romanian legislators to address is the update of biofuels strategies for road and aviation transport, ensuring alignment with EU legislation. The goal is to expand biofuels production while simultaneously supporting the development of road infrastructure. To fully exploit the benefits of biofuels and enable companies in Romania to produce and market biofuels at competitive prices, additional investments and financial incentives are essential. This will contribute to the decarbonization targets imposed on Romania as an EU Member State. Currently, biofuels remain more expensive to produce than fossil fuels. Additionally, biofuel feedstocks have a lower energy density than crude oil, requiring larger biomass quantities to produce the same energy output as fossil sources. From a legislative perspective, it is necessary to establish clear provisions, harmonized with EU regulations, detailing the conditions for large-scale biofuel infrastructure development. Transport is a highly sensitive sector in terms of biofuel adoption, particularly as no large-scale sustainable solutions have been developed in Romania to date.

Regarding biogas, the current legislation should be amended to explicitly define and classify biogas as green technology, which has implications for the implementation of the Net Zero Industry Act (NZIA). Given these constraints, existing biofuel technologies are unlikely to fully and immediately replace fossil fuels. However, rapid state-level action is required to ensure Romania remains competitive with other EU Member States, which are already progressing in this field.

It is essential to recognize the role of innovative biofuel technologies in waste management and decarbonization. More importantly, Romania's key energy policy documents should be evaluated through a European lens before adoption, ensuring alignment with EU targets.

An important legislative gap remains the lack of a national mobility strategy. Additionally, a draft Biofuels Act is expected to be developed at the start of the next legislative cycle.

In the aviation sector, both a suitable legislative framework and financial support are necessary. A major challenge is that Sustainable Aviation Fuel (SAF) in Romania is 15% more expensive than conventional fuel, creating cost barriers to adoption.

Furthermore, financial incentives are required to implement biofuels technology. While subsidies are one option, investments in infrastructure adaptation (e.g., storage tanks and fuel blending facilities) are inevitable.

Policy uncertainty, misalignment with European regulations, domestically imposed targets that diverge from EU standards, and institutional complexity pose significant barriers to the adoption and implementation of renewable energy projects.

Therefore, a long-term bioenergy strategy with clear objectives and cross-sector coordination is needed to support major investments and project development at the national level.

Conclusions

Europe and North America are the leading markets for bioenergy, considering their well-established biofuel industries and strict environmental requirements.

In terms of market size, the global bioenergy market is expected to reach around USD 267 billion by 2027, growing at the total annual growth rate of 6.3% between 2023 and 2027. Growth in the market is primarily driven by favourable government policies and incentives promoting the use of bioenergy, advances in biofuel production technologies, and rising demand for clean energy sources.[32]

In 2023, the bioethanol market was valued at USD 83.4 billion, with forecasts estimating growth to USD 114.7 billion by 2028. Bioethanol has diverse applications across multiple industries, with its primary use as a renewable fuel source. It is commonly blended with gasoline in ethanol-gasoline mixtures such as E10 and E85, providing a low-carbon alternative to conventional fuels while reducing greenhouse gas emissions and dependence on fossil fuels.
The bioethanol market is segmented based on feedstock such as starch-based, sugar-based, cellulose-based and others. The bioethanol market has been divided based on end-use industries such as transportation, pharmaceutical, cosmetics, alcoholic beverages and others.

Despite its benefits, several factors limit bioethanol market growth.

First, compatibility issues affect adoption. Ethanol blends such as E10 or E85 may not be suitable for all vehicles, particularly older models and non-flex-fuel vehicles. As a result, some car manufacturers may prioritize other fuel technologies, limiting the market for bioethanol-compatible vehicles.

Second, government policies and incentives shape market dynamics. If policymakers favor electric vehicles (EVs) and provide stronger incentives for their adoption, bioethanol demand may decline. Policy shifts prioritizing electric mobility over liquid biofuels could significantly impact the growth potential of the bioethanol sector.
Additionally, concerns exist over the environmental impact of bioethanol production. The expansion of bioethanol feedstock cultivation can lead to land-use changes, including the conversion of natural ecosystems such as grasslands, wetlands, and forests into agricultural land. This process can contribute to deforestation and biodiversity loss.

To address these challenges, it is crucial to implement sustainable practices in bioethanol production, including responsible land management, efficient water use, and reduced chemical inputs.

At the same time, more pilot projects are needed to validate bioethanol technologies at the national level.

From a legislative perspective, policymakers must consider the complex challenges faced by the oil, gas, and transport industries in adopting biofuels. A comprehensive regulatory approach is needed, ensuring that normative frameworks align with implementation realities to facilitate widespread adoption of biofuels.

[32]https://www.reportlinker.com/market-report/Bioenergy/6753/Bioenergy?term=bioenergy%20industry&matchtype=b&loc_interest=&loc_physical=1011795&utm_group=standard&utm_term=bioenergy%20industry&utm_campaign=ppc&utm_source=google_ads&utm_medium=paid_ads&utm_content=transactionnel-1&gad_source=1&gclid=EAIaIQobChMIz5iDz6C9hgMVNbxoCR0Gvg4SEAAYASAAEgI-AfD_BwE