

WHAT IS E-FUEL?

—THE POTENTIAL OF LOW-CARBON FUEL MADE FROM CO₂ AND H₂—

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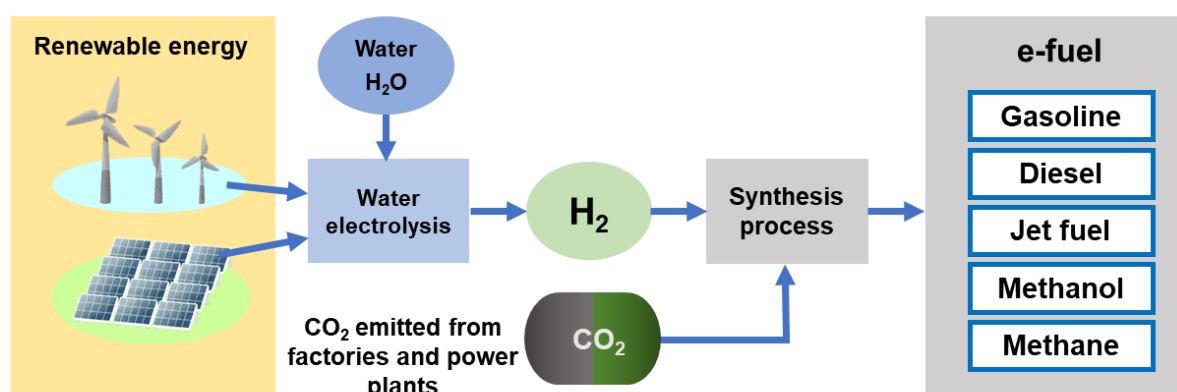
SUMMARY

- An advantage of e-fuel is that it can serve as a carbon-neutral fuel when produced from green hydrogen and atmospheric CO₂. Since it is comparable to fossil fuel in terms of quality, it is compatible with existing infrastructure and engines, making it a viable alternative for transport modes that are difficult to electrify, such as aviation, maritime shipping, and long-haul trucking.
- A major challenge for e-fuel is its higher cost relative to fossil fuels and biofuels, necessitating technological development to improve the efficiency of H₂ production, CO₂ capture, and the overall production process.
- Among the various types of e-fuel, methanol is the most technologically advanced and cost-effective. It is expected to see growing demand as a marine fuel and as a base chemical feedstock.

1. WHAT IS E-FUEL?

e-fuel is a type of fuel synthesized from carbon dioxide (CO₂) and hydrogen (H₂), offering performance equivalent to that of gasoline, diesel, jet fuel, or the like. It can therefore serve as an alternative to fossil fuels. When CO₂ captured from factories, power plants—or even from the atmosphere—is combined with H₂ produced

Figure 1: Overview of e-fuel production



Source: MGSSI

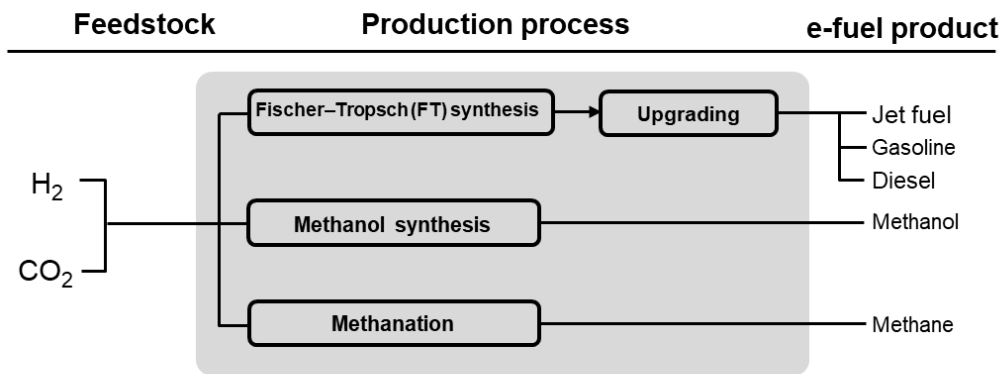
using renewable energy, the resulting e-fuel can be used without generating new CO₂ emissions. This makes it a promising carbon-neutral fuel (Figure 1).

The “e” in e-fuel is said to stand for “electro,” reflecting that the H₂ used as a feedstock is produced by water electrolysis using renewable electricity.¹ The fuel is also sometimes referred to as synthetic fuel, as it is made by synthesizing H₂ and CO₂.

2. TECHNOLOGIES AND CHARACTERISTICS OF E-FUEL

Figure 2 shows an overview of the e-fuel production processes and products. Currently, there are three main production pathways for e-fuel. Gasoline, diesel, and jet fuel are produced using a combination of Fischer–Tropsch synthesis and an upgrading process; methanol is produced via methanol synthesis; and methane is produced through methanation. Each of these processes synthesizes e-fuel from CO₂ and H₂. The following sections will explain how the CO₂ and H₂ feedstocks are produced, as well as the characteristics of each production process.

Figure 2: e-fuel feedstock, manufacturing processes, and products



Source: MGSSI

2-1. H₂ AND CO₂ FEEDSTOCKS

The two main types of H₂ are gray hydrogen, which is produced from fossil fuels such as natural gas, and green hydrogen, which is produced from water by electrolysis using renewable energy. Since e-fuel is intended to help reduce CO₂ emissions, green hydrogen is assumed to be the feedstock.

CO₂ can also be sourced in two ways: from fossil-derived emissions at power plants or steel mills (fossil-derived CO₂), and by capturing it directly from the atmosphere (atmospherically derived CO₂). From a cost perspective, it is more efficient and less expensive to capture CO₂ from industrial exhaust gases, where concentrations range from 10% to 15%, compared to just 0.042% in the atmosphere. However, as explained earlier, atmospherically derived CO₂ is the preferred feedstock for producing e-fuel. For e-fuel to contribute to decarbonization, it is important not to rely on fossil-derived CO₂ but rather to capture it directly from the air, thereby reducing atmospheric CO₂ levels.

Assuming the use of green hydrogen (H₂) and atmospherically derived CO₂ as feedstocks, it becomes important to choose the most efficient and cost-effective production technologies for each.²

¹ Another interpretation of the term’s origin is that it combines the “e” from the German phrase *Erneuerbarer Strom* (electricity generated from renewable energy) with the English word “fuel.”

² Currently, the main technologies for producing green hydrogen are alkaline water electrolysis (AWE), proton exchange membrane (PEM) electrolysis, and solid oxide electrolyzer cell (SOEC) electrolysis. The technology used to capture CO₂ from the atmosphere is known as direct air capture (DAC), which includes chemical absorption, physical adsorption, and membrane separation methods. It is necessary to understand the characteristics of each technology and select the H₂ production and CO₂ capture method based on

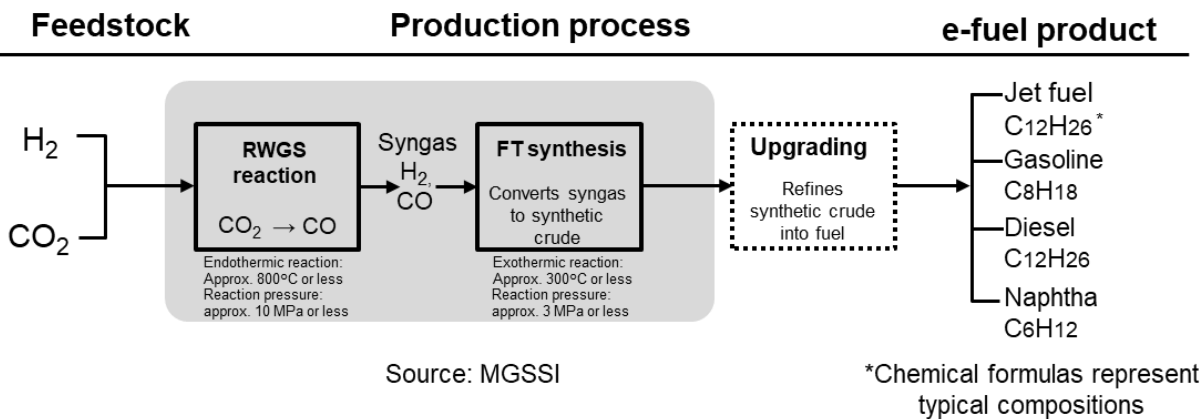
2-2. E-FUELS SIMILAR TO GASOLINE, DIESEL, AND JET FUEL

Figure 3 shows an overview of the production process for e-fuels similar to gasoline, diesel, and jet fuel. This process consists of three main steps: reverse water–gas shift (RWGS) reaction, Fischer–Tropsch (FT) synthesis³, and upgrading. In the RWGS reaction, the H₂ and CO₂ feedstocks are converted into a synthesis gas (syngas) consisting of H₂ and carbon monoxide (CO). CO₂ is chemically stable and unreactive with other substances. Therefore, it must first be converted into the more reactive CO through the RWGS reaction. This step can be considered a form of pretreatment for e-fuel production. In the subsequent FT synthesis step, the syngas (mixture of H₂ and CO) is converted into a hydrocarbon mixture known as synthetic crude. Synthetic crude refers to oil composed of various combinations of carbon and hydrogen. However, it is difficult to yield the target e-fuel alone through FT synthesis.

For example, in FT synthesis to primarily produce jet fuel, the resulting synthetic crude is formulated to contain a high proportion of the target jet fuel (C₁₂H₂₆). However, gasoline-range hydrocarbons (C₈H₁₈) and naphtha components (C₆H₁₄) are also produced. Since multiple types of hydrocarbons are synthesized at the same time, the synthetic crude undergoes refining through distillation in the upgrading process following FT synthesis. This separates the jet fuel, gasoline, and naphtha components, which are then shipped as products according to their respective applications. In addition, processes are applied to reform the hydrogen–carbon bonds in the heavy oil fraction to increase the yield of jet fuel component.

To maximize the jet fuel content in synthetic crude, the key in e-fuel production is to identify catalysts, temperature, and pressure conditions for FT synthesis that match the target fuel type, and to select or develop the most efficient process. The RWGS reaction is an endothermic process that requires external heat and typically uses catalysts such as iron, copper, or nickel, operating at pressures of 1–10 MPa and temperatures of approximately 500–800°C. FT synthesis, on the other hand, is an exothermic reaction that uses iron or cobalt catalysts, operating at 2–3 MPa and around 300°C.

Figure 3: Production process for e-fuels similar to jet fuel, gasoline, and diesel



2-3. E-METHANOL

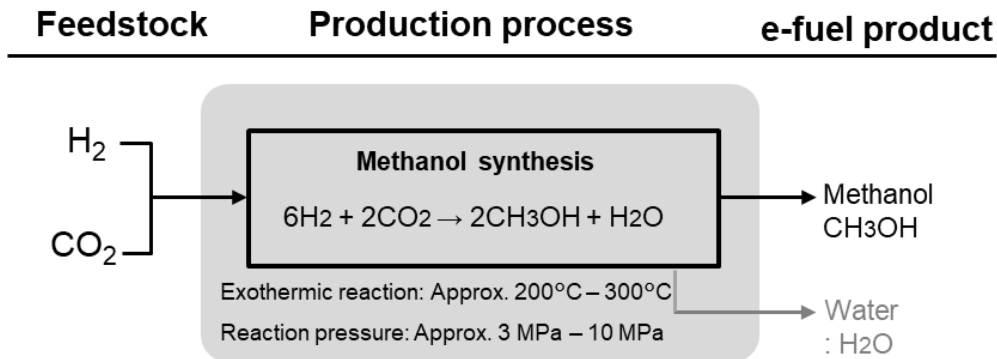
Figure 4 shows an overview of the e-methanol production process. H₂ and CO₂ are converted into methanol through a single-step methanol synthesis process. Unlike the FT-based e-fuel production described earlier, this method does not require a RWGS reaction to convert CO₂ into CO, and can be carried out in a single reactor, making the process relatively simple. Methanol synthesis is an exothermic reaction that uses copper-based

the target e-fuel production volume, the cost and availability of renewable energy at the production site, and the anticipated progress of each technology.

³ The process is called Fischer–Tropsch synthesis because it was developed in the 1920s by German researchers Franz Fischer and Hans Tropsch.

catalysts and proceeds at 200–300°C and 3–10 MPa. Among the various e-fuel production methods, this process is the most technologically established.

Figure 4: Basic e-methanol production process

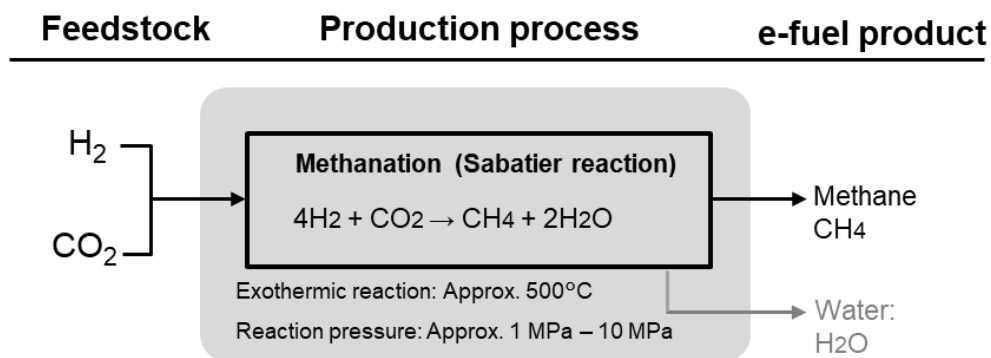


Source: MGSSI

2-4. E-METHANE

Figure 5 shows an overview of the e-methane production process. The synthesis reaction, commonly referred to as methanation, was discovered about 100 years ago by French chemist Paul Sabatier and has long been known as the Sabatier reaction. In this reaction, CO_2 and H_2 are brought into contact with a catalyst such as ruthenium under conditions of 500°C and 1–10 MPa to synthesize methane. Although the reaction was discovered over a century ago, large-scale e-methane production has not yet been carried out. This is because the reaction is highly exothermic at 500°C, and if heat is not efficiently removed, it becomes difficult to control the reaction, posing a risk of accidents. While short-duration reactions in small laboratory setups are feasible, implementing the process in large reactors at chemical plants has been considered technically challenging.

Figure 5: e-methane production process



Source: MGSSI

Figure 6 summarizes the production processes for each type of e-fuel. As the world moves toward carbon neutrality by 2050, research institutions and companies have begun working to scale up e-methane production to commercial levels. The next section introduces projects currently underway to develop various types of e-fuel in this context.

Figure 6: Summary of e-fuel production process

e-fuel	Process	Temperature conditions	Characteristics and challenges
Jet fuel gasoline, and diesel	RWGS reaction + Fischer-Tropsch (FT) synthesis Refined by upgrading	RWGS: 800°C, endothermic reaction FT Synthesis: 300°C, exothermic reaction	<ul style="list-style-type: none"> Established technology RWGS reaction is endothermic and requires external heat input Requires a two-step reactor for RWGS and FT synthesis Catalyst development is important to improve yield of target products
Methanol	Methanol synthesis	300°C exothermic reaction	<ul style="list-style-type: none"> Established technology Exothermic, but can be handled with existing technology
Methane	Methanation (Sabatier reaction)	500°C exothermic reaction	<ul style="list-style-type: none"> Technology under development Reaction control by heat removal is difficult due to high temperature exothermic reaction

Source: MGSSI

3. E-FUEL PROJECT EXAMPLES

Figure 7 shows examples of e-fuel projects. In the area of jet fuel, production is expected to begin from 2025, with development led by companies in the US and Europe, such as HIF (US), Infinium (US), and Ørsted (Denmark). Regarding methanol, the oldest case of commercial e-methanol production dates back to 2012, when Carbon Recycling International (Iceland) used H₂ produced from geothermal power to manufacture e-methanol. In recent years, numerous projects have been advanced by Chinese companies such as Boyuan Chemical. In Europe, companies like European Energy are also developing the technology.

Figure 7: Overview of major e-fuel projects

Company	e-fuel	Production output (million gallons/year)	Start of production	Location	H ₂ source	CO ₂ source
HIF	Jet fuel gasoline, methanol	509	2028以降	Australia, US	PEM water electrolysis	Fossil-derived Biogenic
Infinium	Jet fuel, diesel, naphtha	38	2026	US	Water electrolysis	Fossil-derived
Orsted	Jet fuel	164	2025	Germany	PEM water electrolysis	Biogenic (DAC planned)
Twelve	Jet fuel	0.04	2025	US	PEM water electrolysis CO ₂ electrolysis	Fossil-derived Biogenic
Sunfire	Jet fuel	13	2026	Norway	PEM water electrolysis CO ₂ electrolysis	Biogenic
Carbon Recycling International	Methanol	1.3	2012	Iceland	PEM water electrolysis	Geothermal- associated CO ₂
Boyuan Chemical	Methanol	3.3	2024	China	PEM water electrolysis	Unknown
European Energy	Methanol	10.7	2024	Denmark	PEM water electrolysis	Biogenic
Osaka Gas	Methane	10 Nm ³ /h	2025	Japan	SOEC electrolysis CO ₂ electrolysis	TBD

Source: Compiled by MGSS based on various sources

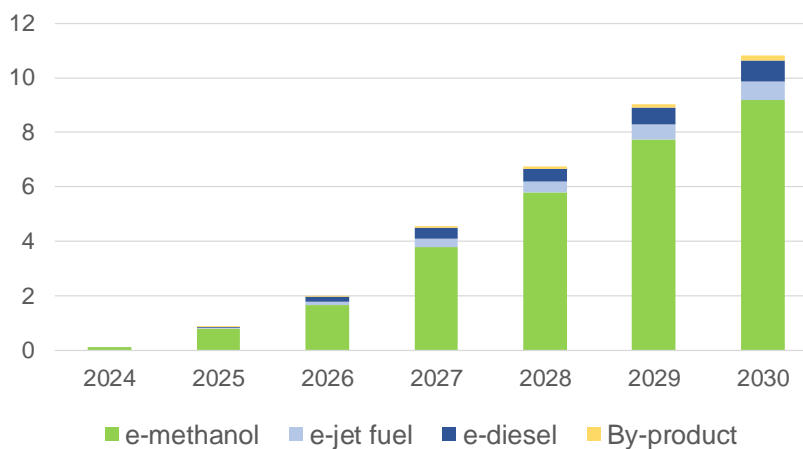
As for methane, Osaka Gas is currently developing e-methane under the Green Innovation Fund Program implemented by the New Energy and Industrial Technology Development Organization (NEDO). The company plans to construct a small-scale plant capable of producing 10 Nm³/h in 2025, followed by a demonstration plant at commercial scale (400 Nm³/h) around 2030. Japan's Ministry of Economy, Trade and Industry has set a

target of replacing 1% of city gas with e-methane by around 2030. Under NEDO's leadership, development by gas suppliers is being promoted, with a strong focus on achieving commercial-scale e-methane production.

4. E-FUEL PRODUCTION OUTLOOK

Figure 8 shows an e-fuel production projection through 2030. Production is expected to reach 0.85 million tons annually by 2025 and approximately 11 million tons by 2030. About 80% of this will be methanol, with jet fuel and diesel making up the remaining 20%. The large share of e-methanol is likely due to its well-established production technology, commercial scalability, and expected demand as marine fuel and a base chemical feedstock.

Figure 8: e-fuel production forecast



Source: Compiled by MGSSI based on IDTech

e-fuel is attracting attention as part of broader climate change mitigation efforts, and policy support is advancing in many countries. In the EU, the ReFuelEU Aviation and FuelEU Maritime regulations were adopted in 2023 as part of the Fit for 55 package, which aims to cut greenhouse gas emissions by 55% by 2030. As a result, long-term policy measures are being developed, including the setting of targets for the introduction of e-fuel and other renewable fuels, in the aviation and maritime sectors. In the US, the Inflation Reduction Act (IRA) has established tax incentives for businesses that use CO₂ to produce fuel or chemicals. With such national-level targets and policy support, e-fuel adoption is expected to continue gaining momentum.

5. CHALLENGES AND PROSPECTS FOR E-FUEL

Currently, e-fuel is two to four times more expensive than fossil fuels or biofuels. Countermeasures include reducing the procurement cost of feedstocks such as H₂ and CO₂, and developing technologies to improve production efficiency while ensuring safety. In Europe, regulatory trends are emerging that require the use of atmospheric or biogenic CO₂ as feedstock in order to justify and maximize the CO₂ reduction effect. This could eventually restrict the use of fossil-derived CO₂, which is currently available in large volumes from industries such as steelmaking, cement, and power generation, posing a potential barrier to commercialization.

Despite these challenges, producing fuel from the greenhouse gas CO₂, and renewable H₂, is considered a leading-edge decarbonization technology. With continued policy support for technology development and cost gap mitigation, its adoption is expected to advance.

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