Green Methanol

2023

JCDREAM

JOINT CENTER FOR DEPLOYMENT & RESEARCH IN EARTH ABUNDANT MATERIALS

CH_2ARGE

CONSORTIUM FOR HYDROGEN AND RENEWABLY GENERATED E-FUELS

Methanol

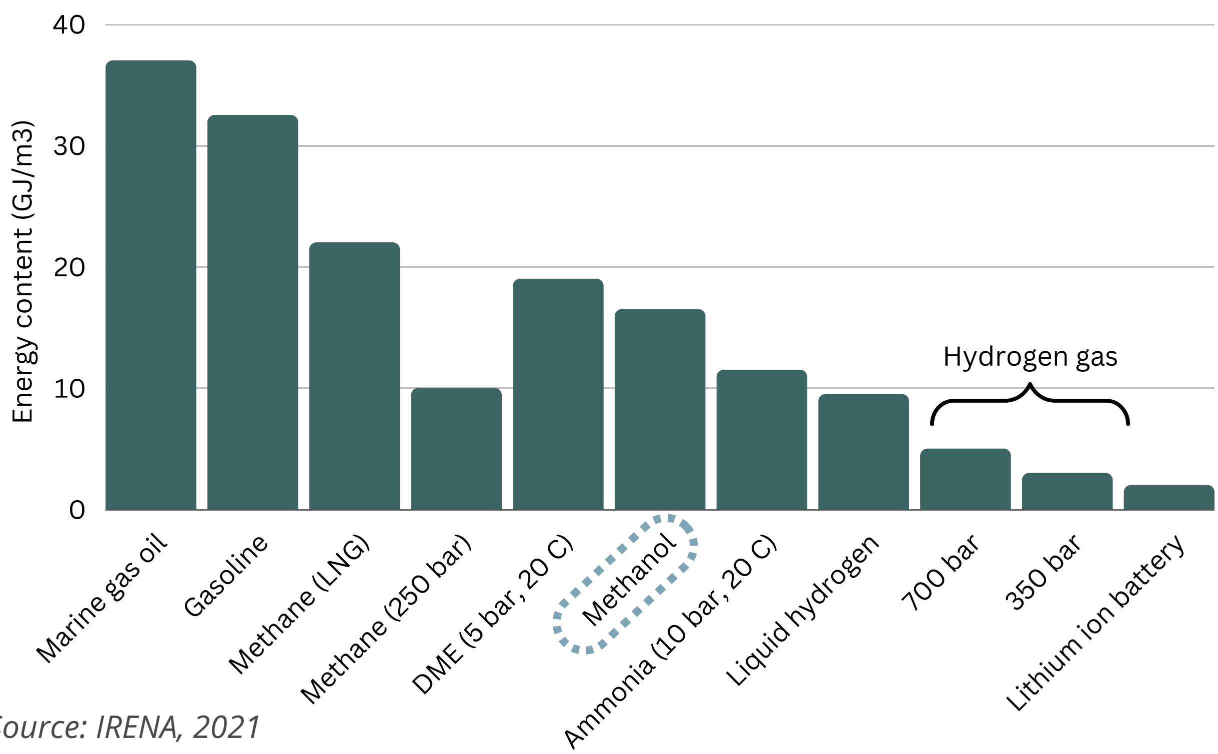
PROPERTIES OF METHANOL

Methanol (chemical formula CH_3OH) is the simplest alcohol and one of the four basic chemicals used in the production of plastics, acetic acid, and formaldehyde. These uses account for about 65% of methanol use cases. The remaining supply of methanol is used as a fuel itself, blended with gasoline, or in biofuel production.

Methanol presents as a flammable, colorless liquid at atmospheric pressure and ambient temperature, which makes it easy to store and move in trucks, ships, pipelines, and rail. It can be used in direct-methanol fuel cells, combustion engines, boilers, and cookstoves, and can also be used as a hydrogen carrier.

Methanol's energy density is relatively low – about half of the volumetric energy density of gasoline and diesel but two times higher than the energy density of gaseous hydrogen compressed at 700 bar.

Figure 1. Volumetric energy density of methanol and other fuels



Source: IRENA, 2021

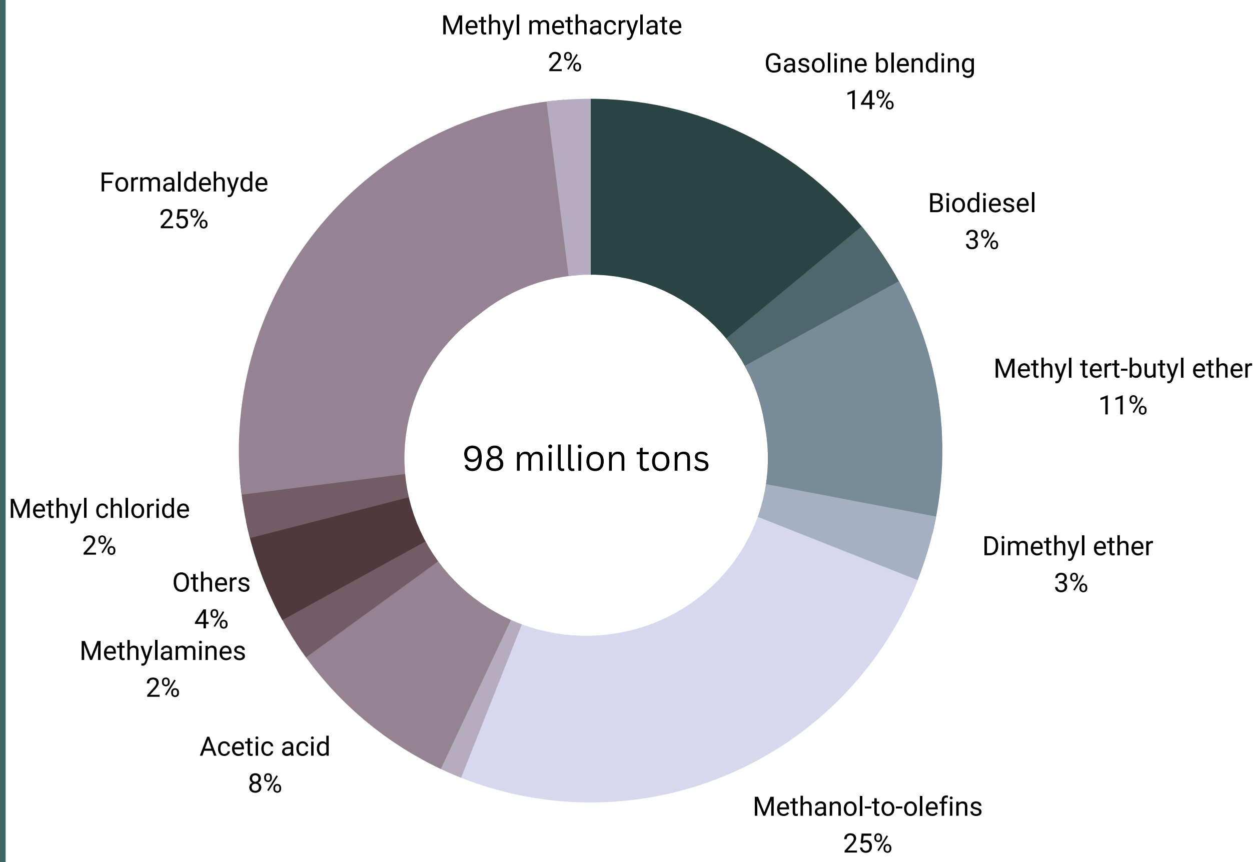
CH2ARGE

METHANOL DEMAND

Worldwide demand for methanol has nearly doubled in the last decade, with most of the growth originating in China. Today methanol is made from fossil fuels, but it can also be made from any feedstocks that contain carbon and hydrogen. These hydrocarbon feedstocks include biomass, biogas, waste streams, municipal solid waste (MSW), black liquor from the pulp and paper industry, and CO2 from flue gas or direct air capture (DAC). These types of feedstock produce bio-methanol.

An alternative pathway to producing green e-methanol (from renewable energy) is through using DAC and green hydrogen. According to IRENA, only 0.2 Mt of renewable methanol is produced annually.

Figure 2. Breakdown of methanol demand sources



Source: IRENA, 2021

CH2ARGE

HYDROGEN IN E-METHANOL PRODUCTION

Production of a methanol molecule requires three hydrogen molecules per CO2 molecule and releases one water molecule as a by-product. Thus, to produce one ton of methanol, about 1.38 tons of CO_2 and 0.2 tons of hydrogen are needed.

$$CO_2 + 3H_2 \rightleftharpoons CH_3OH + H_2O$$

Conventional large methanol plants have a capacity of around 2,500 tons per day. It would take a hydrogen production facility at gigawatt scale to replace this size of methanol plant.

METHANOL PRODUCTION COSTS

Conventional, fossil fuel-based methanol production occurs at a large scale, driving costs for this method down. The cost of methanol produced this way, from coal and natural gas, is estimated at $100-250/ton.

Renewable methanol technologies are just entering the commercial stage with production costs ranging from $350-800/ton. Over time, technology maturity, economies of scale, and carbon credits will bring the costs of renewable methanol closer to fossil fuel-based methanol but input costs are still high. Sources of biomass and municipal solid waste (MSW) are limited, making scale-up of these production processes difficult. Further, the cost of producing e-methanol can be up to $800-1,600/ton fully renewable inputs such as green hydrogen and DAC remain expensive.

TRADITIONAL METHANOL **$100-250/ton**	Fossil fuel inputs Oldest technology Economies of Scale
RENEWABLE METHANOL **$350-800/ton**	Bio/waste stream inputs Entering commercial stage Feedstock supply still limited
E-METHANOL **$800-1,600/ton**	Same technology as above, with DAC and green H2 feedstock Dependent on costs of newer inputs that will fall as tech matures

The cost of e-methanol production is largely determined by the electricity costs associated with green hydrogen production, CO_2 production, and the synthesis of methanol.

Let us assume 100% efficient electrolysis as a benchmark for calculation purposes. In such case, production of 1 ton of hydrogen requires 39.4 MWh of electricity (closer to 50 MWh per ton in practice), with $3 kg/H2 at the lowest electricity price (4 cents per kWh), $560 worth of hydrogen is needed to make 1 ton of methanol. If the price of renewable hydrogen reaches $1 per kg, then the cost of this feedstock will come down to about $190 per ton of methanol, a price competitive with grey and blue methanol.

The price of CO_2 depends on its source and the amount of energy required to purify and compress it. Currently, the lowest CO_2 prices are from facilities that are already producing large amounts of CO_2 such as plants processing or burning fossil fuels.

Renewable CO_2 from biomass using carbon capture technology can cost between $40 and $400 per ton.

CO_2 from biomass gasification and gasification of black liquor from paper mills offer the least expensive CO_2, around $20-100 per ton.

CO_2 coming from direct air capture (DAC) is the most expensive with costs varying from $300-600 per ton. DAC CO_2 is expected to fall to $50-150 per ton as technology scales up and efficiency grows.

It should be noted that DAC is a favorable method of production because the atmosphere is the most sustainable source of CO_2 availabe.

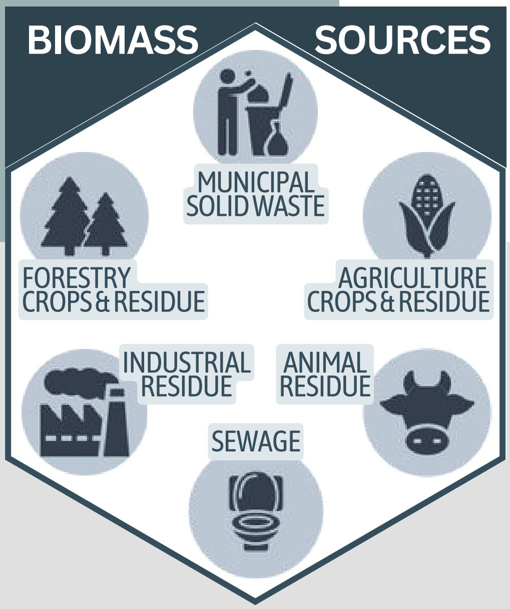
Commercial production of e-methanol began in Europe in 2011 in regions where inexpensive energy was available, and it has proved a viable business case. Now, e-methanol projects in China, Australia, Canada, and the EU have proven feasible due to available inexpensive renewable energy.

The planned capacity of these projects would supply over 7 Mt per year of e-methanol per year by the mid-2020s, providing a feedstock for e-kerosene (jet fuel) and renewable maritime fuel.

METHANOL PRODUCTION PROCESSES

The production process for traditional and renewable methanol is similar, the primary difference being the feedstock.

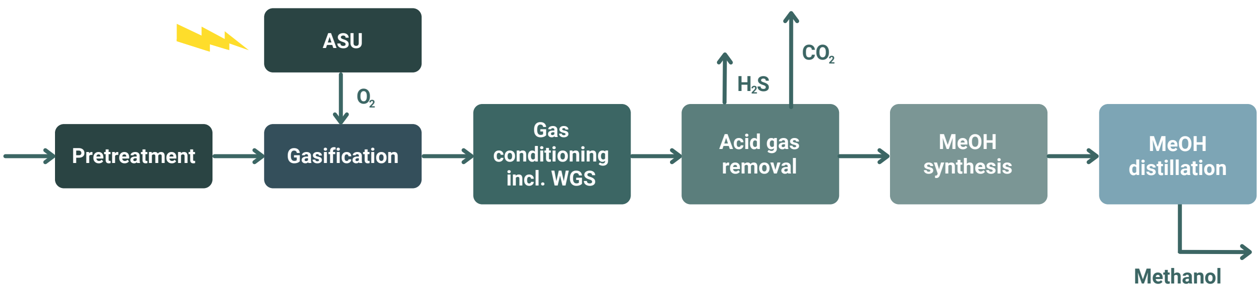
Renewable methanol production involves feedstock pretreatment; gasification into syngas – a mixture of carbon monoxide and carbon dioxide (CO and CO_2), hydrogen (H_2), and water (H_2O); a water-gas shift reaction increasing the amount of hydrogen; gas cleaning; methanol synthesis and purification.



The technological challenge for renewable methanol production stems from its biomass feedstocks. Using bio feedstocks and waste stream inputs often requires homogenization of the feedstock mass before treatment to ensure a consistent feeding rate into gasifier.

Liquid feedstocks like black liquor from pulp and paper mills simplify the feeding line design. Due to the challenges of managing solid feedstocks, methanol production from biomass or MSW at large-scale plants has not gained significant operating experience.

Figure 3. Renewable methanol production process



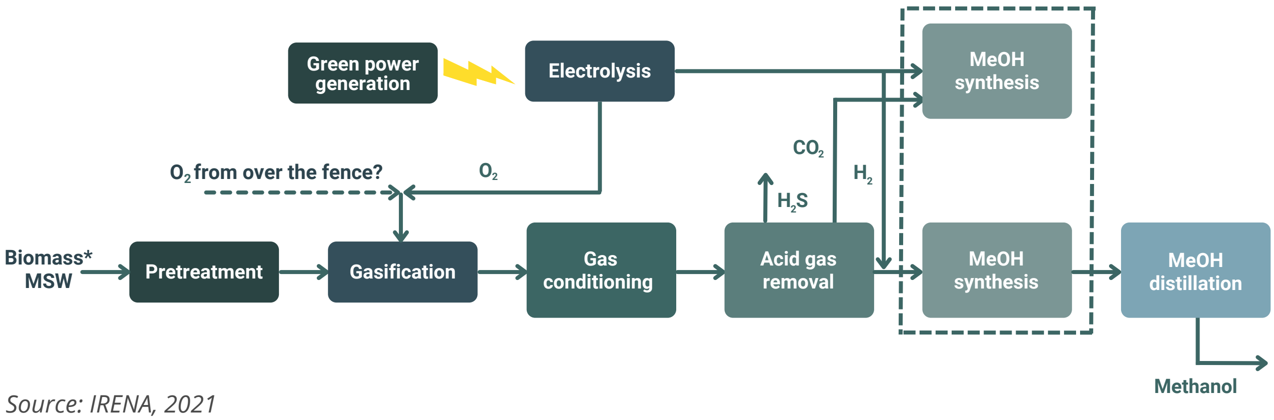
Source: IRENA, 2021

ASU – air separation unit; MSW – municipal solid waste; WGS – water-gas shift reaction

E-methanol production (Figure 4) is a one-step catalytic process converting CO_2 and green hydrogen through Power-to-X technology. There are three main methods to produce e-methanol, with methods 2 and 3 below only having been tested at lab scale.

1. Water electrolysis followed by catalytic reaction of the green hydrogen with CO_2;
2. Electrolytic production of syngas components (CO_2 and H_2) followed by converting syngas into e-methanol as in the conventional methanol process;
3. Conversion of CO_2 and water directly into methanol through electrolysis.

Figure 4. E-methanol production process



Source: IRENA, 2021

The catalytic process for e-methanol synthesis is a well-developed technology. It uses a copper, zinc, and aluminum catalyst with slight modifications to produce more water during the synthesis of e-methanol. Typically, these catalysts operate at temperature ranges of 200-300 Celsius and pressures under 50-100 bar. A number of vendors including Haldor Topsoe, Johnson Matthey, and Clariant offer this technology.

Another attractive possibility under consideration in the industry is a combination of bio and e-methanol production. The carbon efficiency of biomass gasification is around 50% due to the low H_2/CO ratio of syngas. Because of this ratio, half of the CO_2 produced is released into the atmosphere. If biomass conversion is combined with hydrogen, it will allow the capture and use of nearly 100% of the carbon from the biomass.

METHANOL USES

Methanol's usability as a fuel has been gaining momentum since the mid-2000s. Since it burns without producing particulate matter emissions, soot, or fumes it can be used for in-home heating and cooking.

China has encouraged methanol for household uses and for vehicles that run on M85 (85% methanol/15% gasoline), M100 (100% methanol), or GEM fuels (gasoline/ethanol/methanol blends).

METHANOL STORAGE AND TRANSPORTATION

Methanol is already a widely used and shipped commodity available at more than 100 major ports. Storage is fairly simple since it does not require high pressures. Handling liquid fuel at ambient temperature is less technologically constrained than LNG or liquified hydrogen. If methanol was to replace gasoline and diesel, only minor and inexpensive changes in existing storage and delivery infrastructure would be required.

Its refueling stations and end-user experiences are similar to those of gasoline and cost a fraction of hydrogen fueling stations. However, using methanol as a fuel would require adjustment to typical fuel tank sizes in most use cases due to its lower energy density compared to gasoline.

When used in diesel engines, it is necessary to use a small amount of diesel pilot fuel, which undermines decarbonization efforts, or install glow plugs. This is due to the low reactivity of methanol. Alternatively, as a hydrogen carrier methanol can be cracked on-board a vehicle and fed into a fuel cell.

Many automakers including Ford, GM, Honda, Mazda, Toyota, and Daimler have created methanol-powered FCV prototypes. The US deployed several methanol fuels programs from 1980-1990. Despite performance comparable to gasoline, limited methanol refueling infrastructure resulted in user dissatisfaction. Then, falling oil prices made methanol-powered light-duty vehicles uneconomical.

METHANOL AS A MARINE FUEL

The maritime shipping industry represents up to 90% of international trade and is responsible for 9% of the greenhouse gas (GHG) emissions from the transportation sector. With the International Maritime Organization aiming to halve GHG emissions by 2050 and introducing more stringent regulations on emissions, the shipping industry is looking for economical solutions, and methanol can become one.

Methanol burns much cleaner than traditional maritime fuels and can reduce the emissions – Particulate Matter, NOx, SOx – by more than 99%, 95%, and 60-80% respectively. It is readily biodegradable and less hazardous for aquatic organisms than diesel or marine gas oil (Methanol Institute, 2016).

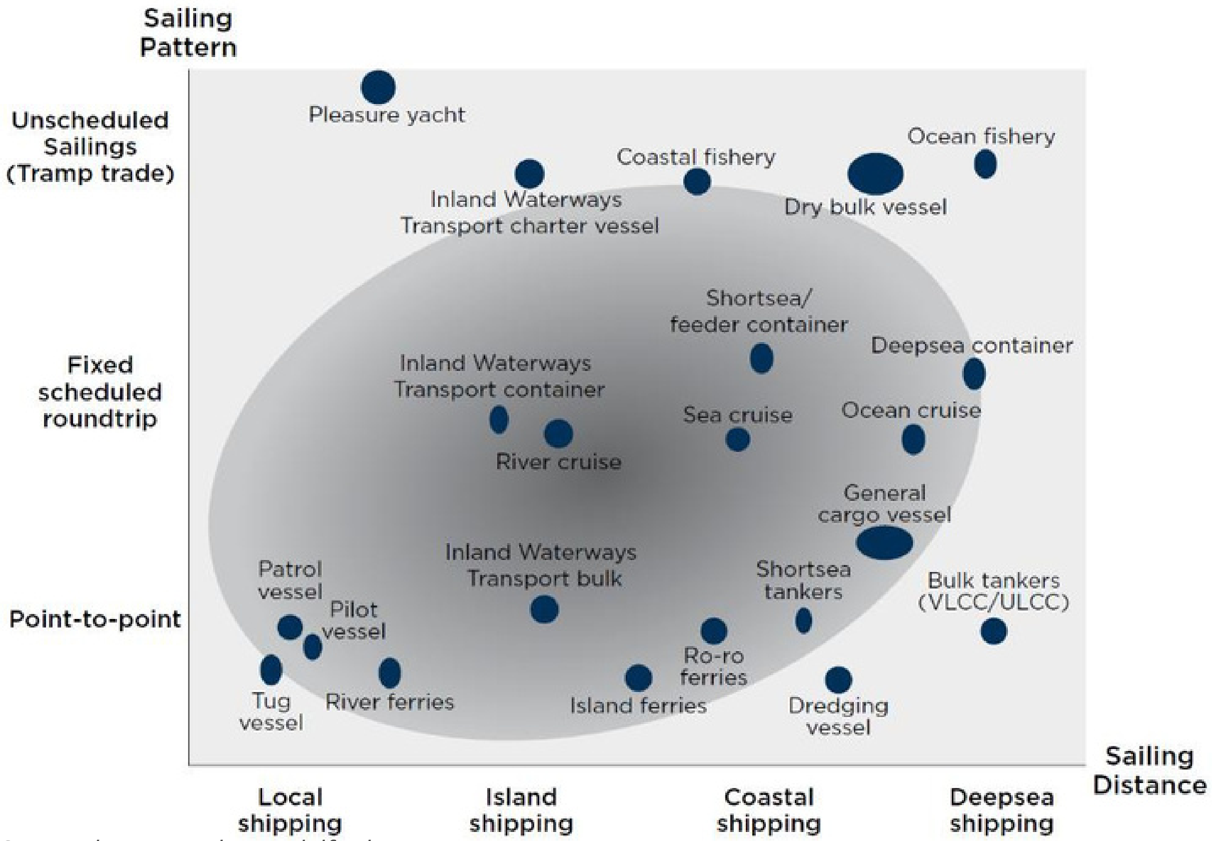
There is a growing expert consensus that methanol is a versatile and economic fuel that can help the maritime industry meet its medium-term decarbonization goals.

Methanol as a Marine Fuel	
ENVIRONMENTAL	Low emissions Safe, environmentally friendly Biodegrades rapidly in water
AVAILABILITY	Available globally Long history of safe handling Existing, straightforward storage infrastructure
VIABILITY	Successfully in use today Commercialization activity expanding

CH2ARGE

Today, companies like ThyssenKrupp or MAN Energy Solutions offer dual-fuel engines that will allow retrofitting of existing vessels within a reasonable time horizon and cost. About 20 large ships were powered by methanol in 2019 (DNV, 2020). Current engines have already shown satisfactory performance with methanol blends, although tank capacity will have to be increased for vessels with higher operating ranges. This makes methanol a great solution for shorter-range vessels, but not ideal for deep-sea vessels (Figure 5.)

Figure 5. Heatmap of methanol applicability by vessel type.



Source: http://resolver.tudelft.nl/

IMPLICATIONS FOR THE PACIFIC NORTHWEST

Utilizing methanol appears economically attractive in emission control areas like the west coast of the United States. In addition, the Pacific Northwest has a developed pulp and paper industry, great potential for cheap renewable hydrogen production at scale, as well as a cruise ship lines and developed ferry system that are looking to decarbonize their operations. **The region is well poised to launch e-methanol production and augment use of renewable fuels in marine vessels.**

Sources

ABS. 2020. Pathways to Sustainable Shipping

IRENA. 2021. Innovation Outlook: Renewable Methanol

MAN Energy Solutions. Methanol in Shipping

Methanol Institute. February 2016. Methanol as a Marine Fuel

JCDREAM

JOINT CENTER FOR DEPLOYMENT & RESEARCH IN EARTH ABUNDANT MATERIALS

CH_2ARGE

CONSORTIUM FOR HYDROGEN AND RENEWABLY GENERATED E-FUELS