E-FUELS AND THEIR POTENTIAL ROLE IN **DECARBONIZING TRANSPORT IN THE EU**

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Transport (including aviation and shipping) accounted for 27% of total greenhouse gas emissions in the EU-28 in 2017. Heavy duty vehicles are currently responsible for 27 % of road transport carbon dioxide (CO2) emissions. Maritime and aviation accounted for 11% and 13% respectively of greenhouse gas emissions in 2017. It is difficult to reduce the fossil carbon footprint of these transportation sectors, because we still do not have developed emission-free propulsion systems for them. E-fuels, sometimes known as synthetic fuels, have the potential to substantially reduce the climate impact of these fossil carbon intensive transport sectors in a relatively short time

Liquid carbon e-fuels are synthetic fuels made by combining green hydrogen produced by electrolysis of water with renewable electricity and captured CO2.

The term "green hydrogen" denotes that the electricity used to electrolyze water was supplied exclusively from renewable sources. CO2 derived from biomass combustion and direct air capture (DAC) are clearly preferred for producing e-fuels because they lead directly to a closed CO2 cycle. There is possible capture fossil CO2 from flue gas from industrial sites (power stations, cement, steel plants, etc.). CO2 collected from the fossil fuel industry is not fully carbon neutral, such as CO2 extracted for example, from biomass combustion (Figure 1). Aside from that, providing fossil CO2 feedstock for the production of e-fuels may encourage fossil industries to continue relying on fossil fuels.

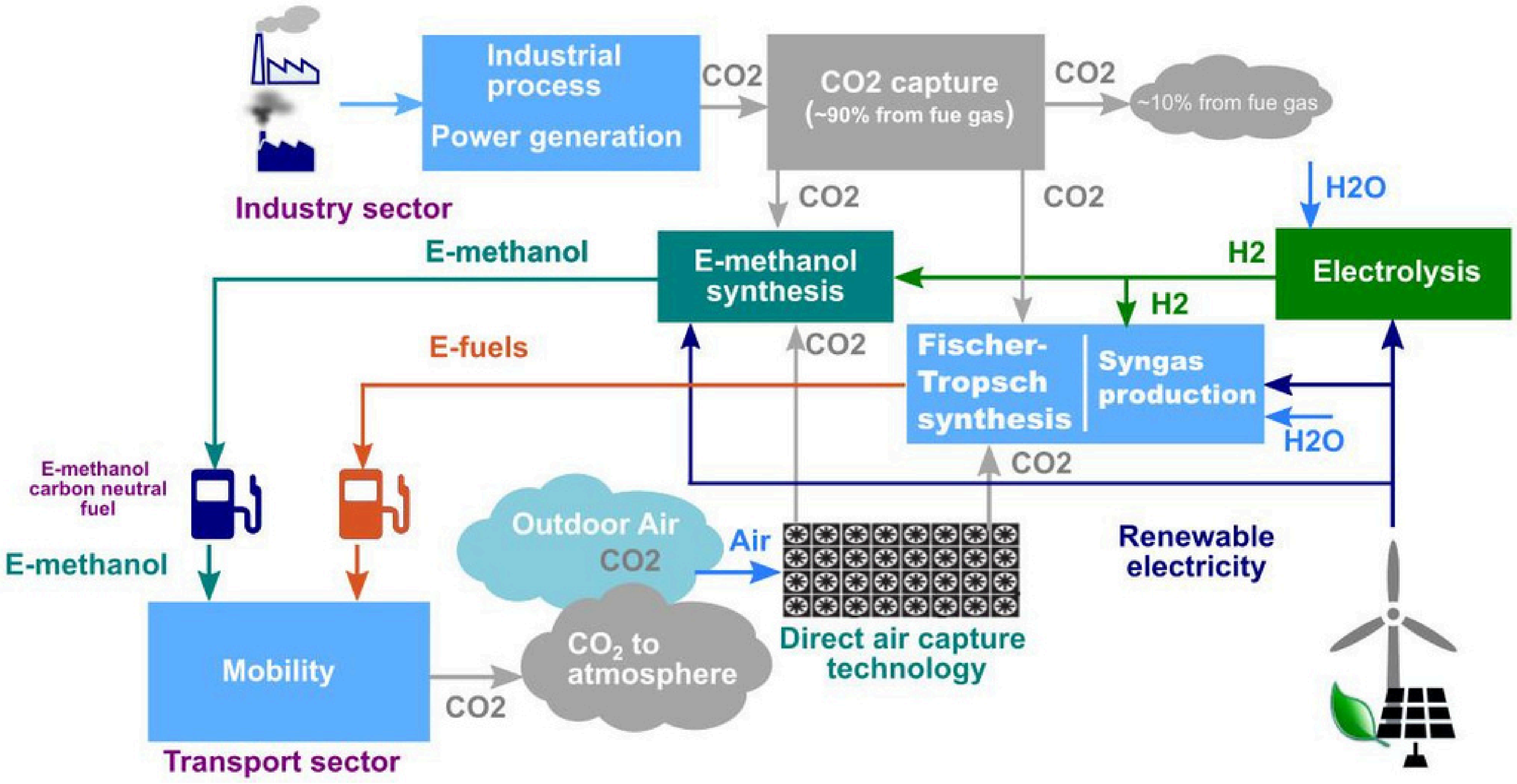


Figure 1.

Why should liquid carbon e-fuels be promoted over biofuels?

E-fuels provide a more scalable source of renewable energy compared to biomass feedstocks used for biofuels. The most crop-based biofuels and certain “advanced” biofuels are not as sustainable as they appear. Expansion of biofuel production in the EU has increased prices for food grains, oilseeds, and vegetable oils.

Biodiesels are predominantly produced from refined vegetable oil and bioethanols are made from corn. But when biofuels are produced from feedstocks that would have been used for food, then biofuels directly reduce potential food supplies. The production of food-based biofuels reduces the land devoted to food production. Deforestation and destruction of ecosystems due to plantation expansion is a big issue in utilizing edible oil as biodiesel feedstock in the developing countries of Africa, Asia, Latin America, and Australia/Oceania. Sure, there is possible to produce biofuels from non-edible oil crops such as Jatropha (Jatropha curcas), karanja (Pongamia pinnata), polanga (Calophyllum inophyllum), etc. It is used to be claimed that these non-edible oil crops can grow on waste as well as on marginal lands. However, there is no guarantee that they will not be grown on land used for food production. Something like that would result in a severe food shortage and its security. Aquatic plants (algae, microalgae and other various seaweeds) could become a promising source of biofuels. but the cultivation of algae (like the cultivation of most other aquatic plants) requires large amounts of phosphorus as a fertilizer, and the Earth's phosphorus reserves are pretty limited. Producing biofuels from lignocellulosic biomass is not easy as well, because the strong bonds that hold lignin polymers together make it very difficult to break down.

E-fuels could become an alternative to biofuels, but the question is whether green hydrogen can be produced in sufficient quantities in the future to meet the requirements for the production of these fuels. Another problematic issue is the cost and availability of green hydrogen, as well as the cost and availability of CO_2. We won't be able to respond to these questions right now, so let's focus on the technical aspects of e-fuel production.

Due to the state of the art of existing propulsion systems, sustainable e-fuels and biofuels are the only the way how to reduce fossil CO_2 emissions. Our existing electric battery propulsion systems would add significant weight to aircraft, heavy-duty trucks, locomotives, etc. Other propulsion systems necessitate technical complexity, and their overall effectiveness is disputable. Even if a new emission-free propulsion system suitable for this sector is developed in the near future, we will be unable to decommission all of these vehicles, due to their high cost!

For many years even decades to come, we will need to use liquid carbon fuels to power so many expensive heavy-duty trucks, locomotives, long-lived ships/airplanes, etc. that we still have in our operation now.

We believe that sustainable e-fuels will play an important role in the defossilization of this sector. We would like to emphasize that e-fuels are still carbon fuels, and their combustion produces roughly the same amount of CO_2 as that of their fossil counterparts. It is reminded here because there exists a general misconception that e-fuels are CO_2 emission-free. They aren't, but their CO_2 emissions are carbon-neutral.

Another benefit besides their carbon neutrality is that e-fuels do not contain impurities such as heavy metals, sulfur, but their combustion still produces particle pollution, NOx, CO and CO2. E-fuels have a positive impact on air quality, because they can produce less harmful pollutants like sulfur, heavy metals, and they may contain reduced quantities of particles and aromatic chemicals that produce soot.

Liquid carbon e-fuels advantages

E-fuels are able to achieve significant fossil CO2 reduction, because their combustion generates carbon-neutral CO2 emissions.

There is possible to use existing infrastructure - liquid fuels distribution infrastructure (pipelines or entire rolling stock can continue to be used for transportation), storage facilities, filling stations, etc.

Some liquid carbon e-fuels may be possible to use to power the whole transport fleet without major changes to their propulsion systems; some liquid carbon e-fuels (e-methanol) require some minor changes in the design of propulsion systems.

There is possible to fully replace conventional fossil fuels with e-fuels or blending e-fuels into conventional fossil fuels to meet required specifications.

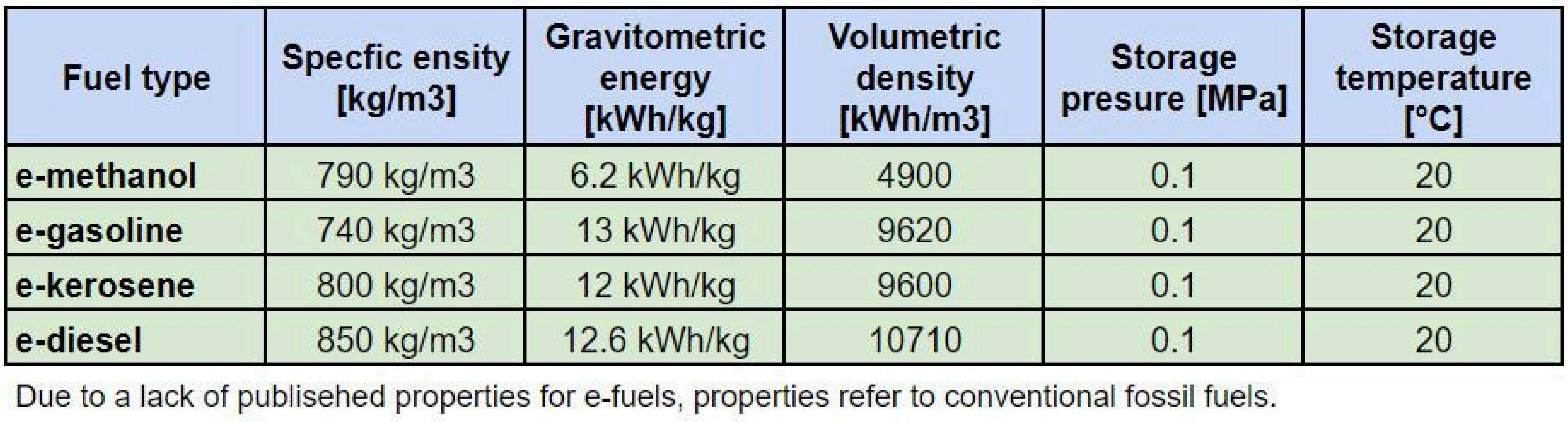
Liquid carbon e-fuels disadvantages

Significant energy losses occur in the e-fuel production process, which translates into high energy consumption from renewable sources.

Well-to-wheel efficiency of internal combustion engines that run on e-fuel is roughly half of engines that run on fossil fuels.

Some characteristics of liquid carbon e-fuels

The main liquid carbon e-fuels produced from geen hydrogen and captured CO2 include e-diesel, e-kerosene, e-petrol, e-methanol. There is possible to see some their properties in Table 1.



Fuel type	Specfic ensity [kg/m3]	Gravitometric energy [kWh/kg]	Volumetric density [kWh/m3]	Storage presure [MPa]	Storage temperature [°C]
e-methanol	790 kg/m3	6.2 kWh/kg	4900	0.1	20
e-gasoline	740 kg/m3	13 kWh/kg	9620	0.1	20
e-kerosene	800 kg/m3	12 kWh/kg	9600	0.1	20
e-diesel	850 kg/m3	12.6 kWh/kg	10710	0.1	20

Due to a lack of publisehed properties for e-fuels, properties refer to conventional fossil fuels.

Table 1.

Potential main uses for liquid carbon e-fuels

There is possible to see the potential primary uses of e-fuels in various modes of transportation in Table 2.

Type e-fuel	Pasenger cars	Heavy duty locmotives	Heavy duty trucks	Aviation	Maritime
e-methanol	X	X	XX		XX
e-gasoline	X				
e-diesel	X	XXX	XXX		XXX
e-kerosene				XXX	

X - an estimation of potential role

Table 2.

Production process of liquid carbon e-fuels

The production process of liquid carbon e-fuels (Figure 2) consisting of e-hydrogen reacting with captured CO2 has two routes:

- methanol synthesis for production of e-methanol
- Fischer-Tropsch synthesis for production of e-liquid hydrocarbons, such as e-diesel, e-gasoline, or e-kerosene

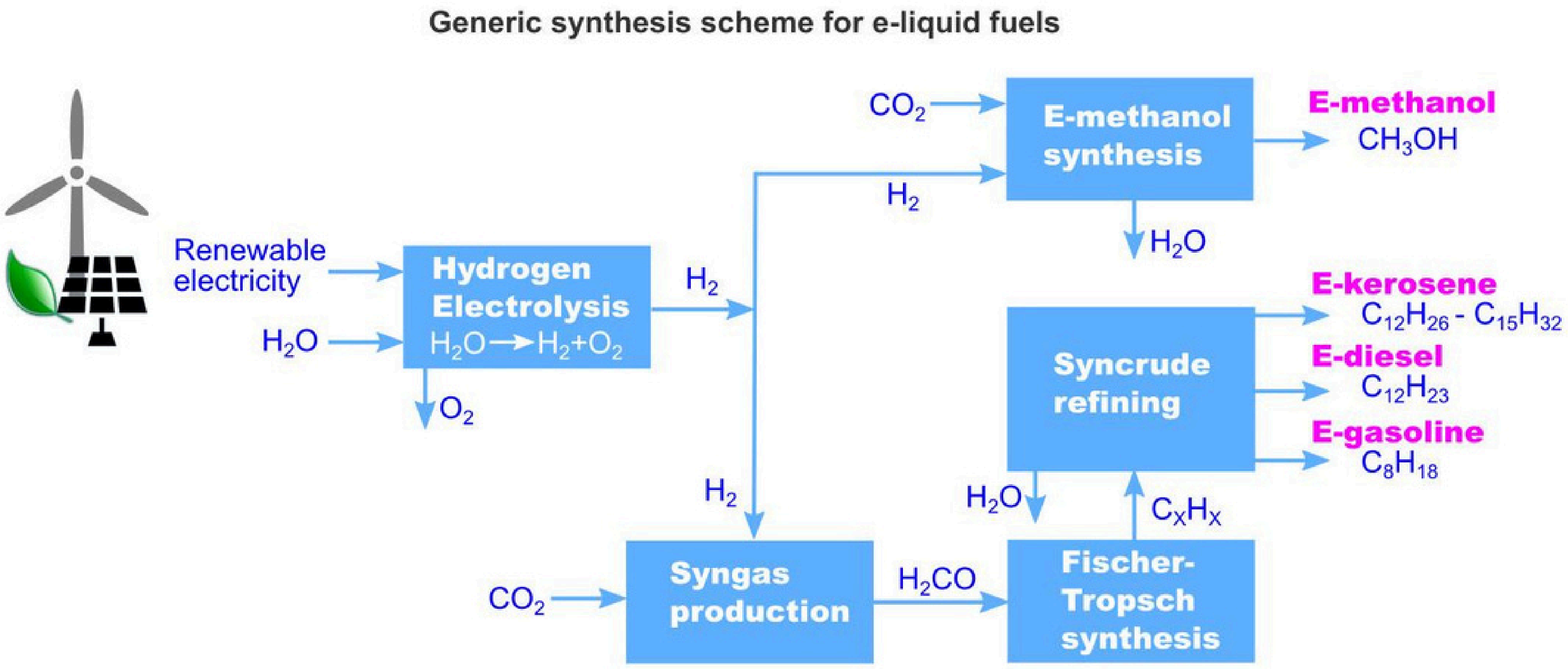


Figure 2.

The production of liquid carbon e-fuels from CO2 and green H2 requires essentially five technological steps: CO2 capture, water electrolysis, syngas preparation, Fischer–Tropsch synthesis, and refining of the Fischer–Tropsch syncrude (sometimes called “blue crude”). Most of the required technologies are well known and widely used in a variety of industrial applications. But, the Fischer–Tropsch reaction requires carbon monoxide (CO) as reactant instead of captured CO2, and therefore, a syngas (a mixture of carbon monoxide (CO) and H2) is necessary to prepare from CO2 prior to feeding the Fischer–Tropsch reactor.

E-methanol is produced through the catalytic hydrogenation of captured CO_2. In the presence of catalysts ($Cu/ZnO/Al_2O_3$), CO_2 reacts with H_2 to form methanol at a pressure of 5-10 MPa, and temperature of 210–270°C (1)(2)(3)(4)(5). Produced methanol is separated from water and residual gases and purified through distillation.

To produce 1000 kg of e-methanol, about 1400 kg of CO_2, ~200 kg of hydrogen and ~1700 kg of water are needed. Around 10-11 MWh of renewable electricity is required to produce 1000 kg of e-methanol; a predominant part of it is used for the electrolysis of water.
Methanol has a specific gravimetric energy density of 6.2 kWh/kg. When 10-11 kWh of renewable electric energy is required to produce 1 kg of e-methanol, the production of e-methanol is 56-62 percent efficient.

To find out how efficient is the production of liquid fuels, we uses information published in a source (6). The overall energy required to produce 1 tonne of e-diesel is 23444 kWh. The specific gravimetric energy density of e-diesel is 12600 kWh/tonne (Table 1.) and it means that production of e-diesel is roughly 50% efficient.

Well-to-wheel efficiency

Well-to-wheel efficiency of internal combustion engines powered by e-fuels is quite low, as is evident in Figure 3. The well-to-wheel efficiency of an ICEV powered by e-methanol is 14 percent, while the well-to-wheel efficiency of an ICEV powered by e-fuel is only 12 percent. The well-to-wheel efficiency is slightly higher in the case of e-methanol, as the production of e-methanol is less complicated; it does not require the generation of syngas from captured CO_2. As already mentioned, high energy losses in production process are a disadvantage of e-fuels.

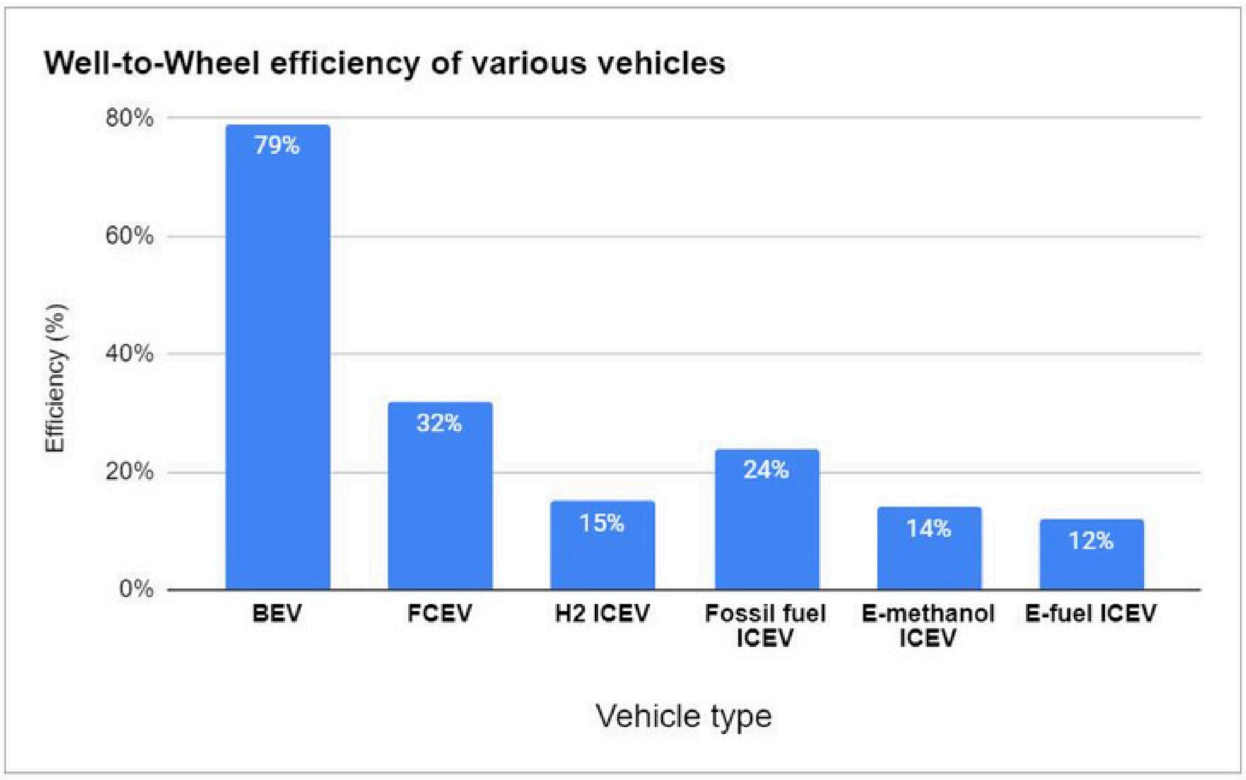


Figure 3.

The current technology for producing e-fuels is still at the demonstration scale. E-fuels have the potential to serve as "bridge" fuels for the short-term decarbonization of planes, ships, heavy trucks, and locomotives until zero-emission propulsion systems for this sector are developed.

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