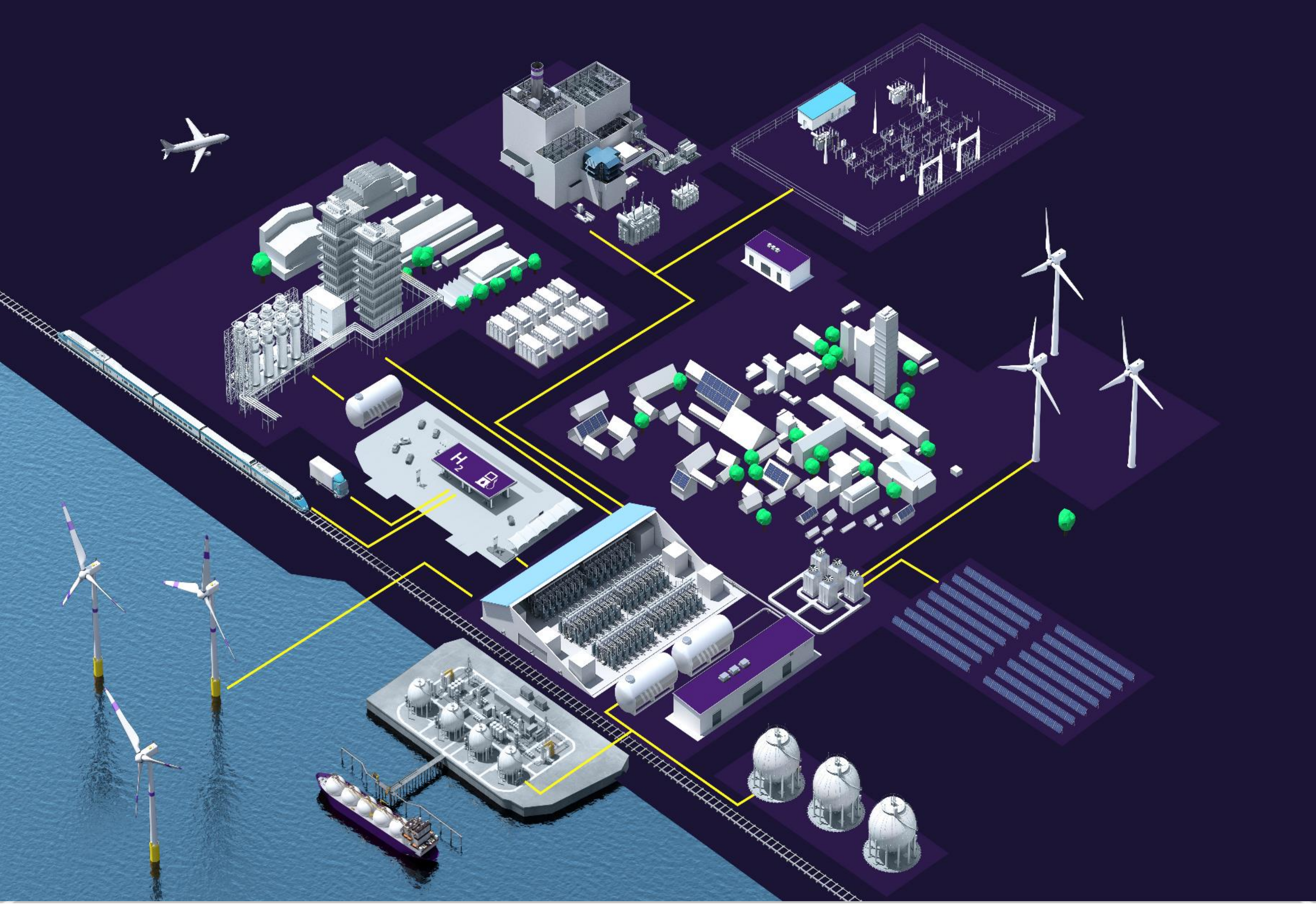


e-Methanol

A universal green fuel

siemens-energy.com

SIEMENS energy

Contents

01 Introduction

02 Methanol – characteristics and conversion processes

03 Economic factors and use-cases of e-Methanol for transport sector

04 Roadmap for implementing e-Methanol

05 An e-Methanol economy – Vison or fantasy?

1 Introduction

Decarbonization of global energy systems

Global emissions of CO_2, the most important greenhouse gas, are continuously increasing and were predicted to reach 33 Gt in the year 2019. While significant progress has been made in the power sector over the last one to two decades, with a growing share of renewable energy sources of roughly 22 percent, the rate of greenhouse gas (GHG) emission in other sectors has stagnated or even increased. In the meantime, governments are putting more and more focus on decarbonizing the transport, industry, and heating sectors.

Today, 40 percent of global emissions are from electricity production (Figure 1). Due to the steadily improving economics of solar PV and wind power generation, and increasing improvements in electricity storage costs, the future decarbonization of the power sector will gradually progress. In contrast, the industry and transport sectors are together responsible for 45 percent of the world’s CO_2-emissions. In these sectors, renewable energy sources (RES) have only reduced emissions by eight percent. Decarbonizing these sectors is more complex and costly compared with the power sector, and it will most likely come from a combination of electrification and carbon-neutral fuels and feedstocks.

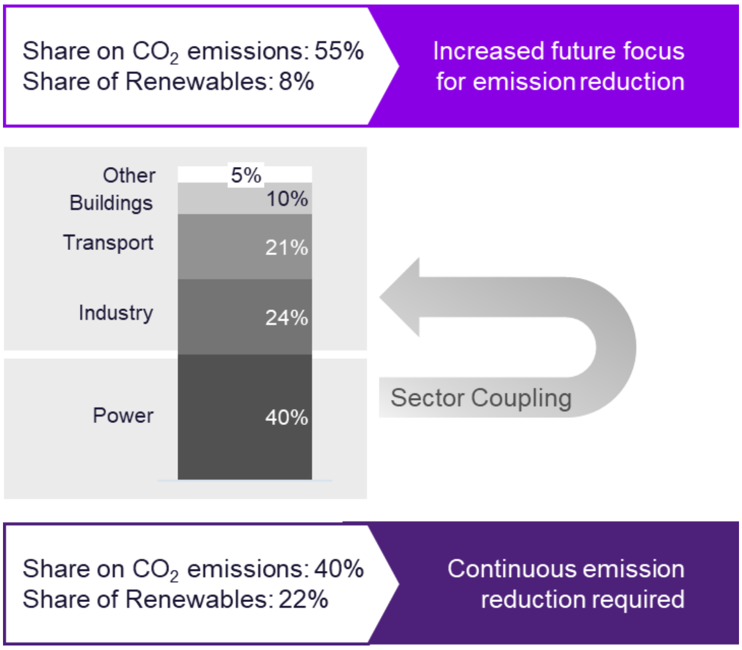


Figure 1: Energy related global CO_2-emissions and their shares by sectors.

It is no surprise, that carbon-free and carbon-neutral energy carriers, that are based on green hydrogen have recently become the focus of attention. Renewable electricity production costs have dropped to levels far below €25/MWh_{el} at many favorable locations around the globe. Green hydrogen and synthetic e-fuels based on renewable electricity are therefore seen as favorites for decarbonizing those sectors, which are not easy to electrify and still use energy carriers with a high carbon footprint.

Carbon-free and carbon-neutral energy carriers

e-Fuels and biofuels are highly relevant for reducing CO_2-emissions, especially in the transport sector. Using existing infrastructures (distribution, filling stations), this sector’s deep decarbonization is expected to come from these carbon-neutral e-fuels. On the other hand, there is a common understanding that global biofuel resources are limited, and thereby their contribution to decarbonizing of energy systems is limited as well. Furthermore, the restrictions on food-based biofuels will become tighter in the future and shrink these resources even more. e-Fuels are perceived as the only option for providing large volumes of carbon-neutral liquid fuels in the future (Figure 2).

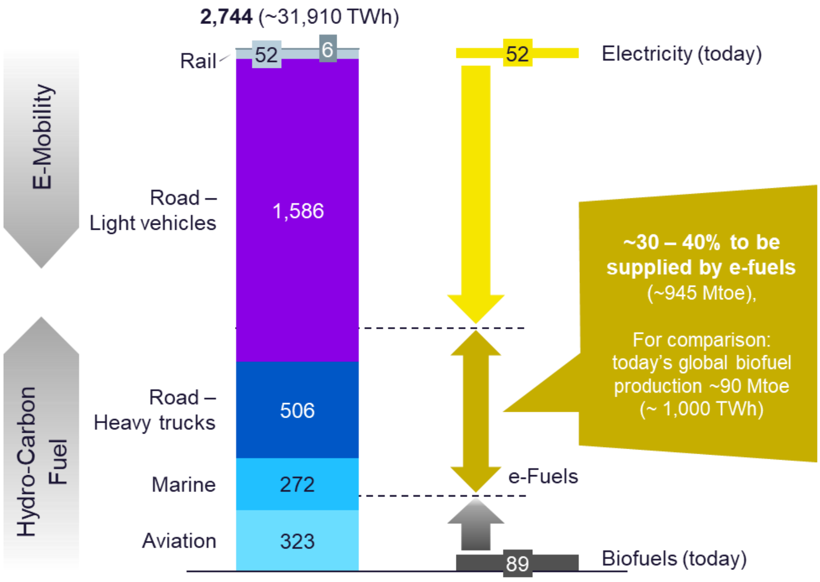


Figure 2: Low CO_2-emission fuel options for global transport in millions of tons (source: IEA statistics 2019)

Compressed gaseous green hydrogen and liquid e-fuels provide important benefits. They are extremely energy-dense, easy to store and in addition to serving as energy carriers, they can be used as carbon-free or low-CO_2 feedstock for industrial and chemical processes. The most prominent hydrogen-based synthetic e-fuels feedstocks are e-Methane, e-Methanol and e-Ammonia. Each has its own characteristics in terms of production process, combustion features, and safety that meet the requirements of their various use cases.

Methanol markets today and tomorrow

Methanol is a universal chemical compound that today is still being produced from coal and natural gas-derived synthesis gas (H_2 and CO). It is used in large quantaties (more than 98 Mt in 2019), primarily as a feedstock for chemicals (80 percent) and in smaller volumes as an energy carrier (20 percent). The largest volumes and strongest growth over the last five years have been methanol-to-olefin conversion and formaldehyde-production. The production of conventional methanol is well established; large-scale methanol plants have a production-capacity of up to 1.5 Mt/a. Figure 3 shows the steady growth in global consumption in recent years.

In the future, non-fossil e-Methanol will see vast new application fields. It becomes sustainable or ”green” when it is produced from renewable hydrogen of either biological (bio-methanol) or electrochemical origin (e-Methanol) and CO_2. This paper focuses on the green hydrogen path, which uses renewable electricity.

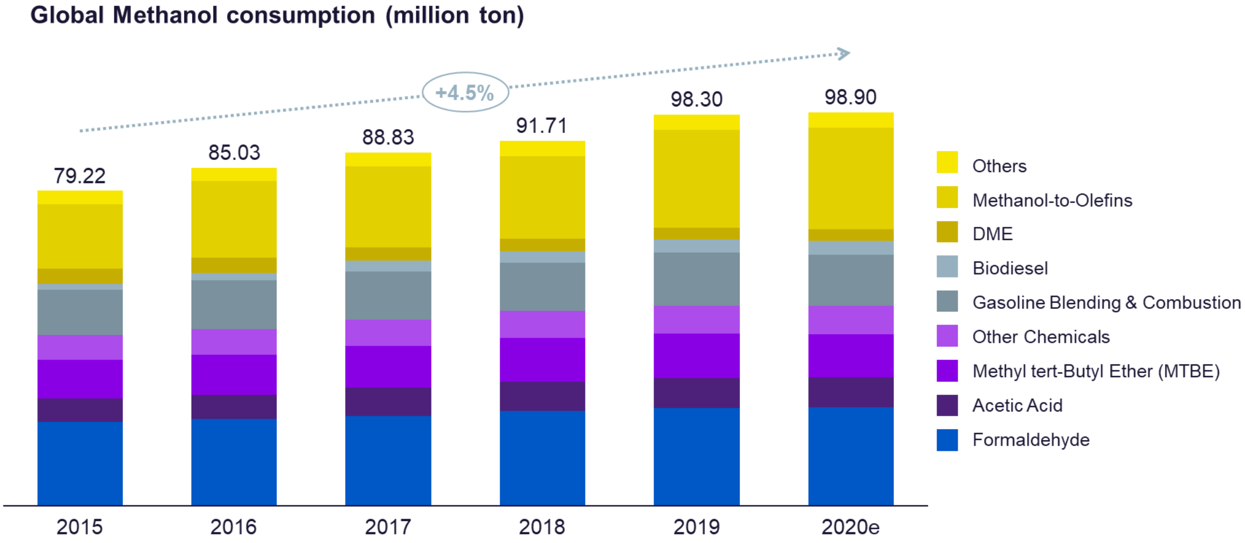


Figure 3: Global annual methanol consumption by application (source: Methanol Institute)

Conventional and e-Methanol are chemically identical but are distinctly different in terms of their CO_2 footprint, which is on the order of 10 g CO_2/MJ_{th} for green methanol and 80-90 g CO_2/MJ_{th} for fossil-sourced methanol. Green e-Methanol belongs in the category of carbon-neutral fuels. This means that its combustion releases approximately as much CO_2 as it gets bound when being produced. CO_2 losses are from the conversion process and transportation and distribution. Independent of the source, reusing emitted CO_2 results in an overall prevention of nearly net 50 percent of CO_2 emissions to the atmosphere, and the CO_2 cycle is closed in principle (Figure 4).

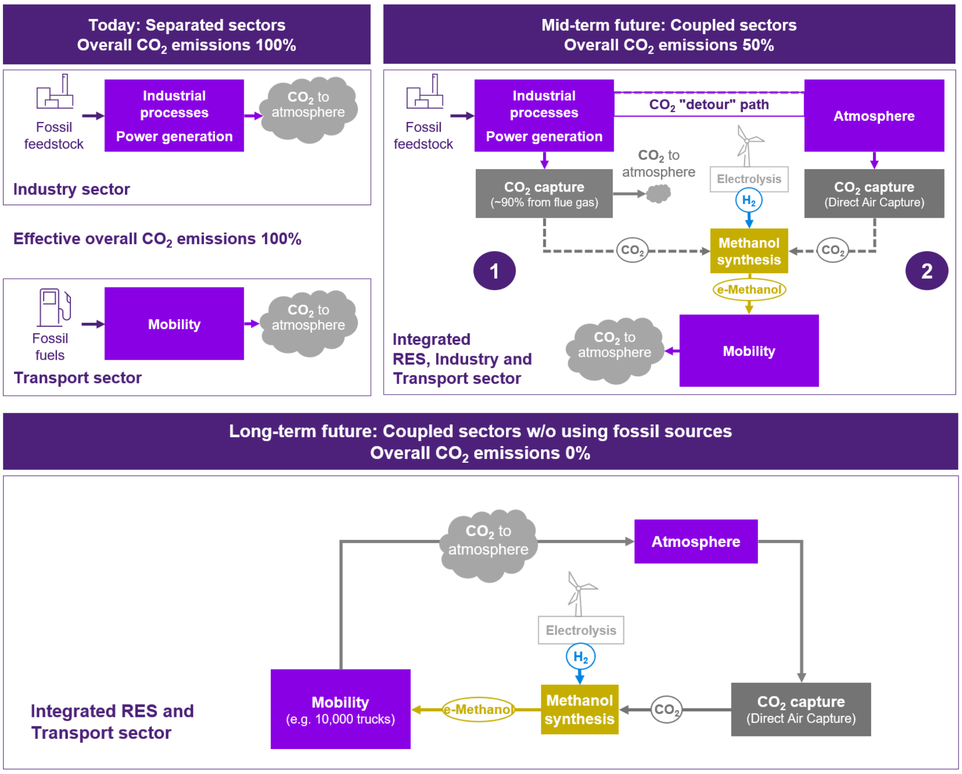


Figure 1: Coupling PtL with industrial CO_2-emissions reduces net CO_2-emissions by up to 50 percent

It is obvious, that the primary energy used to produce largely carbon-neutral energy carrier needs to be green, produced in a dedicated way by renewable electricity. Interactions with electricity grids should be minimized as long as their electricity mix is still linked to CO_2 emissions. On the other hand, integrating Power-to-Liquids (PtL) processes into the existing grids can contribute to the overall power balance and grid stability as an additional and flexibly usable electricity-consuming element (demand-side management). These effects should be considered in the future design of large PtL facilities and their optional grid connections.

2 Methanol: Characteristics and conversion processes

Conventional methanol and e-Methanol

Methanol (CH_3OH) is the simplest alcohol and consists of a methyl group coupled to a hydroxyl group. The single oxygen atom “liquefies” methane (CH_4), and therefore provides significant advantages in handling compared with the gaseous methane (natural gas). Methanol is a light, colorless, volatile, flammable, and water-soluble substance with a distinctive alcohol odor. It is toxic but easy to control, especially in industrial applications. The essential advantage of (e-)Methanol is its high compatibility with existing infrastructure like tanks, pipelines, and fueling stations as well as existing propulsion technologies.

Today methanol is produced primarily from natural gas by means of steam methane reforming (SMR), a mature, highly integrated and cost-effective process. But when derived from fossil sources, the production of this conventional “grey” methanol involves high CO_2 emissions. From an economic perspective, however, it is hard to outperform when the hydrogen is produced from RES and converted with CO_2, due to low natural gas and CO_2 prices.

The synthesis of methanol from H_2 and CO (synthesis gas) and from H_2 and CO_2 are exothermal chemical reactions. When converting it from CO_2, one mol of H_2 (per mol methanol) is lost as water. The process performance is primarily determined by the reaction temperature, pressure and catalyst features. To obtain high conversion rates, internal recycling of the product gas is still required in today’s processes.

One method for partially decarbonizing conventional methanol production from fossil sources uses green hydrogen to balance the potential mismatch of H_2 and CO/CO_2 in the synthesis gas acquired from substances like coal (Figure 5).

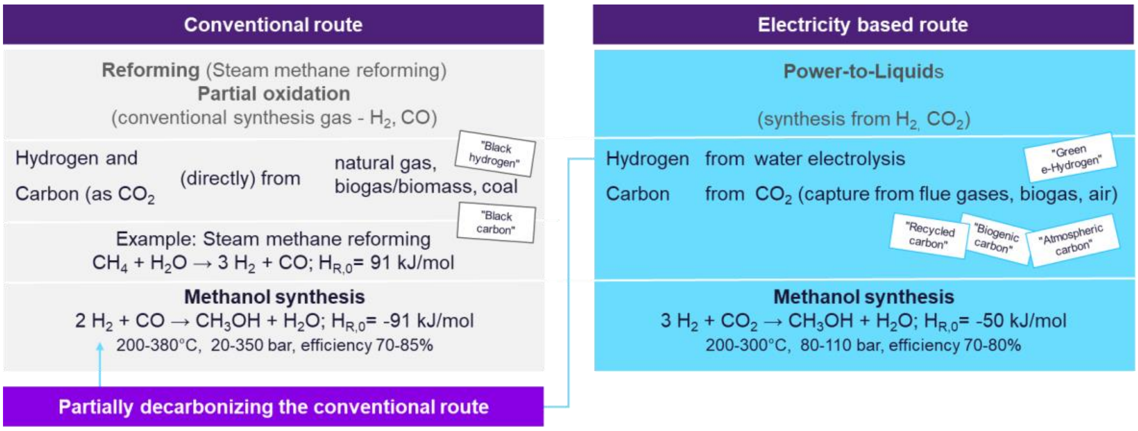


Figure 5: Pathways for synthesizing methanol

CO_2 sources for green e-Methanol

In terms of the chemistry, all CO_2 sources can be used to produce e-Methanol. The CO_2 molecule is identical, whether it is emitted from a coal-fired power plant or from combusting biomass. e-fuels and e-Methanol are determined to be green or sustainable as long as the energy required in the processing is renewable.

However, there is an ongoing dispute about whether CO_2 from combustion processes can be used for green products. There is a concern, that this could lead to a rationale for using fossil fuels and thereby emitting greenhouse gases. Biomass-based CO_2 and CO_2 derived from the air - direct air capture (DAC) - are clearly preferred for producing e-fuels because they lead directly to a short-term closed CO_2 cycle (carbon neutrality). On the other hand, CO_2 emissions from specific industrial sources like cement production and from steel works are mostly inherent, and thereby unavoidable. Re-using the CO_2-emissions for PtL processes has a similar effect and is clearly environmentally benign. Bonding CO_2 from sour gas treatment and natural gas utilization like power generation using highly efficient gas turbines, will be evaluated case by case. Each application field and project will need to be ecologically assessed and the produced e-fuel will be certified by independent institutes for their compliance with all environmental measures including their GHG impact.

Nevertheless, each re-use of CO_2, whatever its source, has similar CO_2 emission conservation effects due to the creation of a CO_2-neutral cycle (see Figure 4). While carbon capture from flue gas is technologically developed to a great extend and the economics are acceptable, DAC technology is still under development. Its technological feasibility has been demonstrated in principle in initial demo-projects, but industrial-grade systems have not yet been built and the capture costs are still too high to implement it in large-scale commercial projects.

However, with the projected decrease of investment and operating costs, DAC will support the production of e-Fuels, even in long-term future poor availability of industrial CO_2 sources. In this way the CO_2 supply will become independent of any fossil sources and thereby PtL projects may be applicable all over the world.

e-Fuels derived from e-Methanol

In addition to the direct use of e-Methanol, the methanol pathway opens the route to other carbon-based CO_2-neutral e-fuels. When e-Methanol is finished by converting it into e-Dimethylether (CH_30CH_3), e-Hydrocarbons (C_xH_y) like e-Gasoline and e-Kerosene will be able to replace their fossil counterparts. The electricity-based fuels become in this manner direct drop-in fuels, which are completely compatible with the existing fossil counterparts. They are synthetically produced and usable in existing engines, turbines and heating systems with no need for extensive modification. Concurrently, all existing infrastructure for fuel transport, storage and fueling can be used without modification. The processes used to convert methanol to higher carbon-chain hydrocarbons are called Methanol-to-Gasoline (MtG) and Methanol-to-Kerosene (MtK).

Nevertheless, today the more common way to produce synthetic gasoline or kerosene uses the Fischer-Tropsch process. e-Diesel and other synthetic products like green-labeled waxes for the cosmetics industry are also produced using this method. The Fischer-Tropsch process uses hydrogen and carbon monoxide as educts; for the green path, the CO_2 needs to first be reduced to CO (see Figure 6).

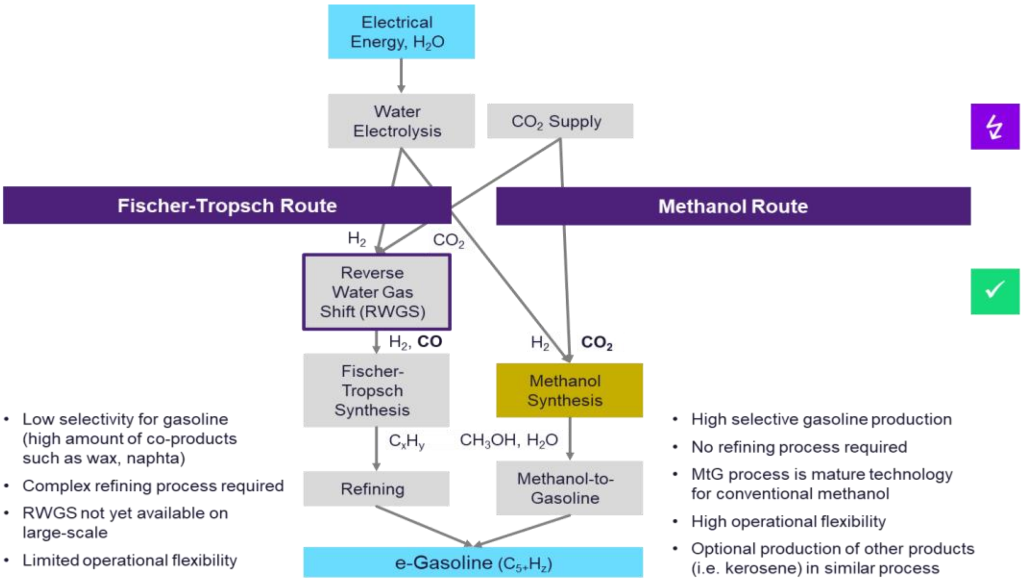


Figure 6: Alternative process pathways for the production of green e-Gasoline

Methanol-to-Gasoline process

ExxonMobil’s MtG-technology is a well-known method for producing certificated gasoline from methanol. The first plants were built in the 1980s, and have demonstrated their high technology-readiness, process performance, and reliability for decades. At that time, the main purpose for investing in this novel gasoline production route was to become independent of crude oil refining.

Today, MtG can support the creation and strengthening an (e-)methanol economy, using e-Methanol as a commodity hub for the gasoline and kerosene supply. The chemical route of the MtG process is based on the intermediate formation of dimethylether (DME) and dehydrogentation. After condensing of the water, the product spectrum typically contains 85 to 90 percent light gasoline (mainly C_{5+} hydrocarbons) and some 10 percent LPG (liquified petroleum gas) as a byproduct (Figure 7).

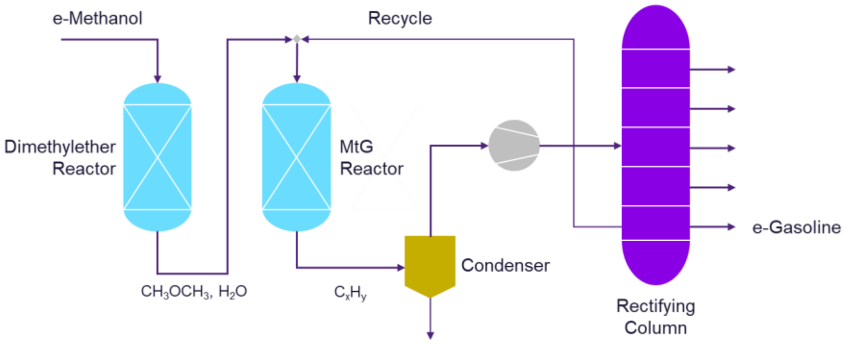


Figure 7: Simplified flowsheet of the Methanol-to-Gasoline process (source: Exxon)

The overall energy efficiency of the conversion process has been assessed at 92 percent. Through the electricity-based route leading to e-Gasoline, a decarbonization rate of about 90 percent compared with the conventional route can be achieved, and - as a synthetic product - e-Gasoline is free of sulfur and nitrogen. The implementation of the latest technologies to produce synthetic e-fuels will also lead to the introduction of e-Methanol in the transport sector.

3 Economic factors and use-cases of e-Methanol for transport

Cost and prices

The electrical energy needed to split the water is the most dominant economic parameter in the e-Methanol production chain. Its share in the final product cost varies between 30 and 40 percent, depending on regional renewable electricity costs. Figure 8 shows the correlation between electricity price and e-Methanol production cost. Under climate conditions beneficial for wind power generation in Europe, green electrical energy can be produced at €25-50/MWh$_{el}$. The electrolysis could be operated at up to 4,500 h/a. These conditions result in an e-Methanol production cost of €800 to 900/t (Figure 8).

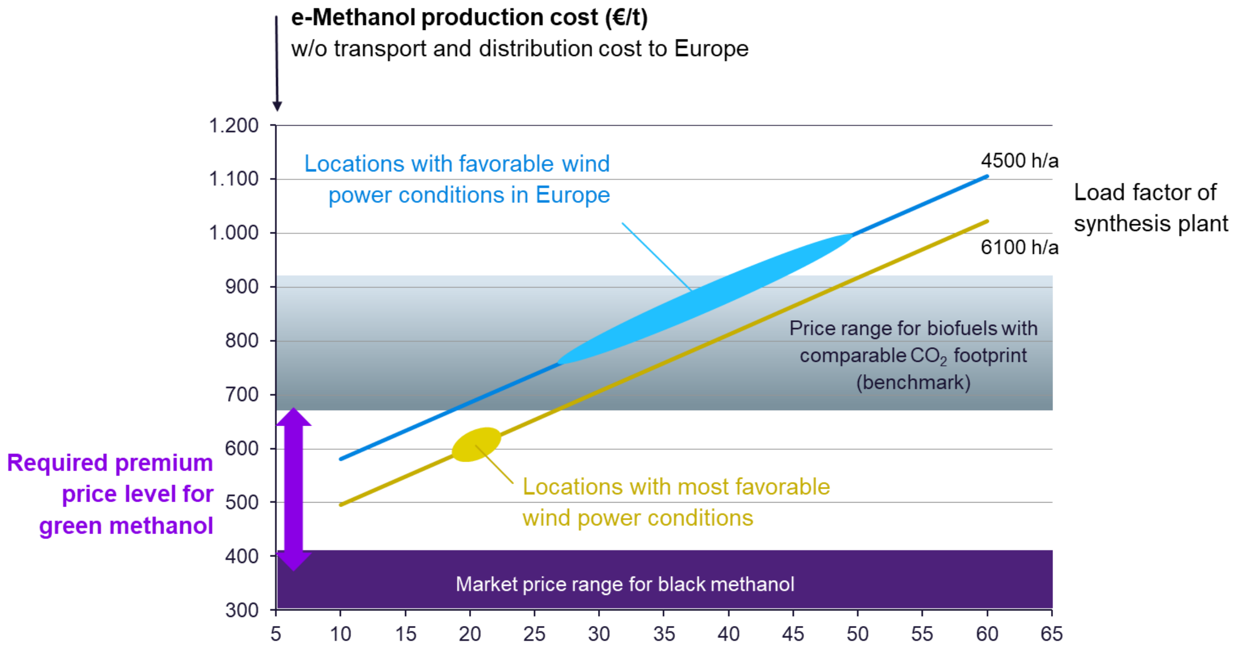


Figure 8: Production cost of e-Methanol based on electricity price

In contrast, in many regions worldwide with the most favorable conditions for generating wind and solar, electricity costs below €20/MWh$_{el}$ and very high load factors for electrolysis are feasible. At these locations, the e-Methanol production cost could be as low as €600-650/t, depending on the cost for CO_2. Our reasons for optimism include the decreasing cost of equipment and project financing. Even when considering costs for an intercontinental transport of about €30 to 60/t to the European end-consumers, the overall cost for imported e-Methanol would be much lower than if it were produced in domestic markets. Furthermore, the potential for generating renewable electricity in central Europe, which is limited also for regulatory reasons, could not possibly match the future demand for e-fuels needed in other countries.

In the past, prices for conventional methanol produced primarily from natural gas have fluctuated significantly between €300 and more than 450/t. Because they are related to the prices of fossil sources, in the future, fluctuating prices for fossil methanol can also be expected. This effect, as well as an increase of CO_2 prices, could make future price calculations uncertain. e-Methanol production cost are dominated by investment costs and are thereby highly predictable and constant, from project launch over the plant’s lifecycle. The current price gap between grey and green products is projected to decrease.

Nevertheless, due to their significantly lower CO_2 footprint, and in order to strengthen the worldwide fuel decarbonization efforts, a price premium for green e-fuels is needed. The situation is comparable to biofuels, for which a market price well above that of fossil gasoline has been already established and accepted in the market. A benchmark for future e-Methanol prices can be evaluated by looking at the bioethanol sector, which recently experienced a drastic increase in prices. Taking into consideration its energy content and CO_2 footprint, e-Methanol prices up to €1000/t seem to be realistic in a mid-term future. This scenario provides a viable business cases for large-scale e-Methanol plants abroad for export to Europe.

Use-cases in the transport sector

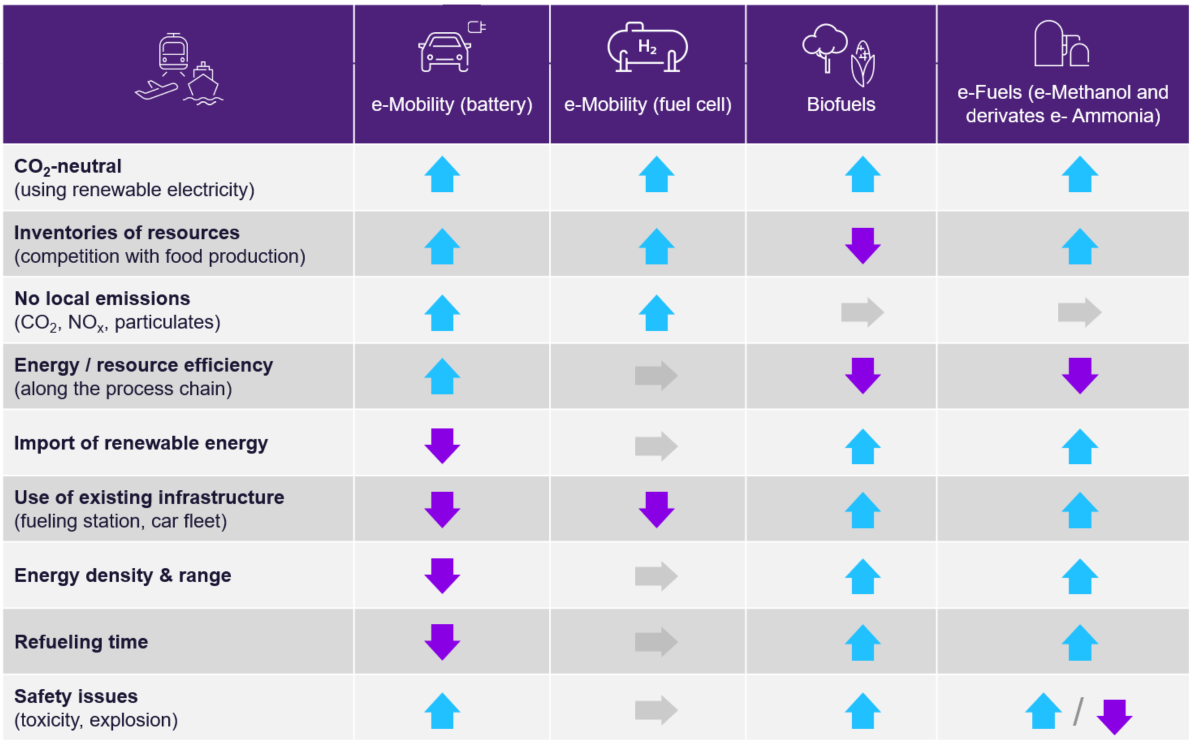
Until now, main approaches for reducing CO_2-emissions from the transport sector have been focused on improving engine efficiency and blending conventional gasoline/diesel with biofuels. However, the remarkable specific emissions savings per car have been compensated by the increase in the car fleet and the popularity of big cars. Over the last decade, multiple low CO_2-emission drive concepts have been introduced to the market, at times triggering controversial discussion.

The most important advances are electrical drives (e-cars), either directly powered from batteries, or from hydrogen via fuel cells. This concept is still facing challenges, including the high cost and low availability of the appropriate hydrogen infrastructure. Conventional biofuels have been successfully introduced to the market, but they are approaching their limits due to insufficient capacity as well as competition with food production. As a novel decarbonization instrument, e-fuels are increasingly considered as serious alternative to other proposed solutions, especially due to their compatibility with established fuel infrastructure. This is an important factor, especially valid for regions with large existing car fleets that also lack the capital for a radical change to battery or hydrogen drives. Most importantly, an immediate conservation in CO_2-emission can be achieved by implementing e-fuels.

All of alternatives mentioned will gain in importance, partly in competition, partly supplementing each other, specifically for each use case, with their individual benefits and disadvantages. Figure 9 summarizes the different aspects.

So far, the global low-carbon fuel markets have been dominated by biofuels. In 2019 roughly 96 Mtoe (million tons oil equivalent) of biofuels were marketed worldwide (IEA). The most important biofuels are bioethanol with a global production of about 57 Mtoe and biodiesel at 39 Mtoe. This corresponds to a share of global fuel consumption in transport sector of roughly 4 percent. Global biofuel production would hypothetically need to triple by 2030 in order to fulfill the projected demand in the 1.5 K global warming mitigation scenarios. There is a common understanding that worldwide biomass resources won’t be sufficient to meet these requirements, especially considering the tighter regulations on biomass resources that were put in place to prevent competition with food production (second generation biofuels).

e-fuels will be urgently needed in order to overcome these shortages. Up to now, their global production has been very limited; only a small number of e-Methanol plants are in operation (see Figure 17). Nevertheless, a future shift to carbon-neutral e-fuels, especially e-Methanol, e-Gasoline and e-Kerosene, could make a significant contribution to efforts to decarbonize the transport sector worldwide.



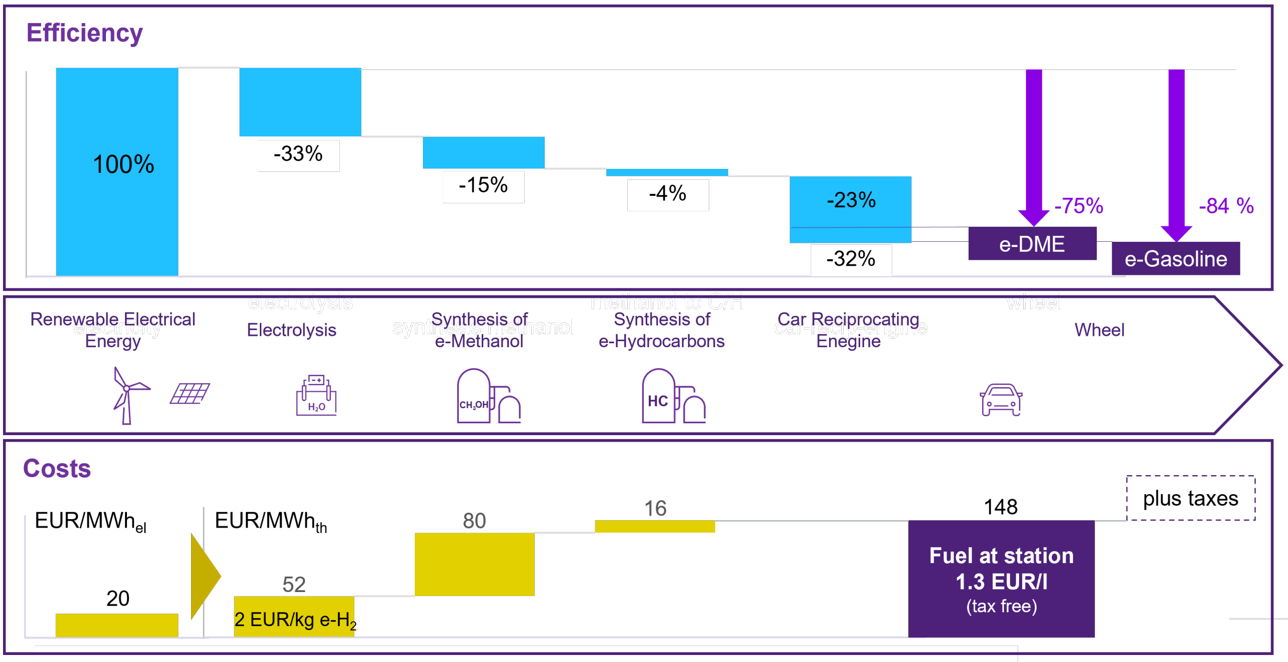
	e-Mobility (battery)	e-Mobility (fuel cell)	Biofuels	e-Fuels (e-Methanol and derivates e- Ammonia)
CO_2-neutral (using renewable electricity)	⬆	⬆	⬆	⬆
Inventories of resources (competition with food production)	⬆	⬆	⬇	⬆
No local emissions (CO_2, NO_x, particulates)	⬆	⬆	➡	➡
Energy / resource efficiency (along the process chain)	⬆	➡	⬇	⬇
Import of renewable energy	⬇	➡	⬆	⬆
Use of existing infrastructure (fueling station, car fleet)	⬇	⬇	⬆	⬆
Energy density & range	⬇	➡	⬆	⬆
Refueling time	⬇	➡	⬆	⬆
Safety issues (toxicity, explosion)	⬆	➡	⬆	⬆ / ⬇

Figure 9: Opportunities for decarbonizing transport sector

In general, if renewable electricity is sufficiently available in a given region, e-mobility based on batteries is preferred due to its high well-to-wheel efficiency. But even in this case, due to their high weight, batteries for long-distance heavy-duty transportation vehicles are most likely not feasible. For these applications, highly energy-dense green hydrogen and especially e-fuels are a better option. And in contrast to electrical energy, they can be economically imported from faraway regions abroad: for example, arid areas that are rich in wind and solar energy but not suitable for biomass production. Synthetically produced e-fuels also contribute to the desulfurization (SO_x) and denitrification (NO_x) of the transport sector. e-Fuels for land mobility can also profit from synergies to shipping and aviation, where e-fuels will need to play an important role in decarbonization.

It is true that the various stages of the conversion chain - from renewable electrical to chemical and finally to motion (for example powering a car) - are associated with different kinds of substantial losses. For land transportation, a well-to-wheel efficiency in range of 15 percent is expected. That is clearly inferior to e-mobility. On the other hand, because renewable resources are infinitely available worldwide and will be technically exploited more and more in an increasingly economical way, the losses in efficiency are of lower priority as long as the final economics are acceptable (Figure 10).

At a first stage, large-scale PtL project at sites with the lowest costs for renewable electricity production, e-Methanol production costs are estimated at €130/MWh_{th}. This corresponds to €150/MWh_{th} for e-Gasoline (about €1.30/l, tax-free).



Assumptions: Today’s investment, central plant, wind load factor ~ 60-65%; WACC 9%; CO_2 price: 80 EUR/t

Figure 10: Energy balance and cost structure of the Power-to-Gasoline process (simplified)

Road transportation

Methanol has been an established additive to gasoline as anti-knock agent for decades. Up to three percent by volume is allowed for blending with conventional gasoline in accordance with European specifications; higher admixture rates are technically feasible (Figure 11). Admixing 15 to 20 percent methanol does not require substantial modification to today’s engines. Eni in Italy has tested a fuel type containing 20 percent methanol; in China regulations for up to pure methanol (M15 ... M100) have been implemented, modified engines are in operation in large car fleets. So far, China’s motivation for using methanol as a fuel for transportation is to become more independent from oil imports and to mitigate local emissions of pollutants from conventional fuels. e-Methanol is becoming increasingly interesting as an easy drop-in option for reducing the mobility’s CO_2 footprint.

The production of biodiesel requires about 10 percent methanol, which today is obtained from fossil sources. Simply replacing it with e-Methanol would also reduce the carbon footprint of biodiesel. Anti-knock agents based on methanol could be easily replaced with decarbonized e-Methanol.

As mentioned, in order to become more compatible with conventional fuels, e-Methanol can be converted into synthetic e-Gasoline (MtG-process). Its CO_2-footprint of approximately 10 g/MJ_{th} would enable a more than 90 percent reduction in CO_2-emissions compared with fossil fuels.

DME is also an excellent synthetic substitute for conventional diesel oil with only minor modifications to modern, highly energy-efficient diesel engines. Largely carbon-neutral e-DME could help decarbonize the transport sector, including buses and freight transportation.

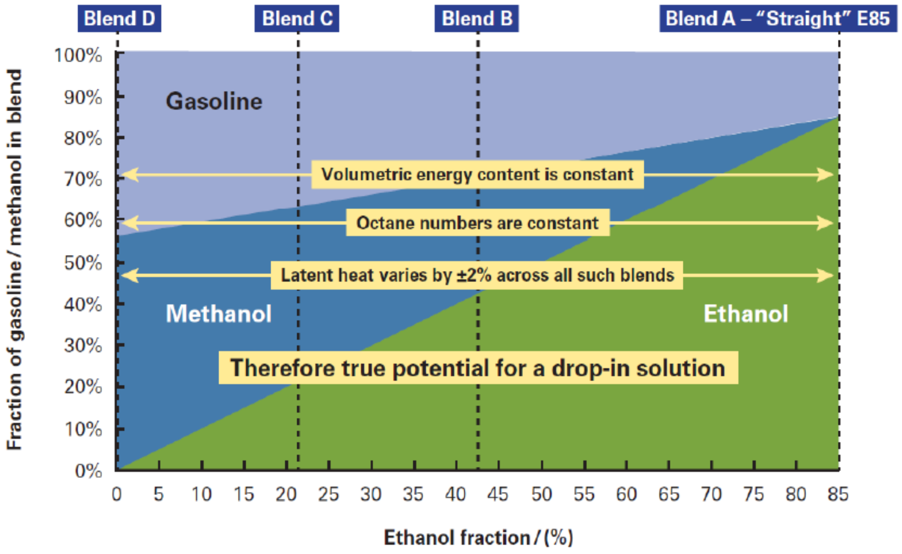


Figure 11: Options for blending gasoline with ethanol and methanol (Source: Turner, Pearson)

Shipping

Like the other transportation sectors, the shipping industry is facing significant challenges resulting from the technological changes forced by global warming. Typical fossil fuels like heavy fuel oil that have dominated this sector for more than 100 years will be replaced by low carbon fuels as the shipping industry urgently seeks to reduce its pollutants and greenhouse gas emissions. Today, shipping accounts for two to three percent of global CO_2 emissions, a share that will rise with growing trade if left unchecked. The International Maritime Organization (IMO) has therefore set a target to reduce emissions by 50 percent in 2050 (relative to 2008, Figure 12). Individual companies are moving ahead with more ambitious goals.

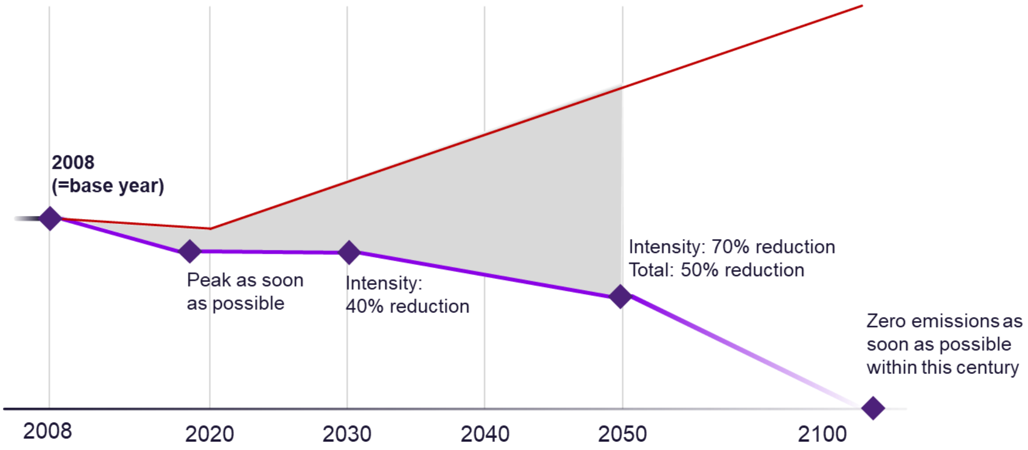


Figure 12: GHG strategy of the International Marine Organization (IMO).
Total: refers to the absolute amount of GHG emissions from international shipping. Intensity: Carbon dioxide emitted per ton-mile. (Source: IMO)

In addition to improving drive efficiency, better logistics, and reducing the transportation velocity, changing the fuels used in the shipping sector is a promising measure for reducing CO_2-emissions. Alternatives to today’s heavy fuel oils include low-carbon or even carbon-free fuels: liquified natural gas (LNG), methanol, hydrogen and ammonia, all of which are clean fuels that are also highly relevant because of the recent more stringent SO_x- and NO_x- emissions restrictions. In a first step, they may be still produced from fossil sources and still charged with associated CO_2 emissions. Nevertheless, the shift toward the green electricity-based variants can be made smoothly for existing fleets and for new ships, immediately leading to a huge reduction of CO_2 emissions. However, today it is an open question as to which of these e-fuels will prevail in the shipping sector over next 10 to 30 years. Each has its advantages in different use cases. Future shipping will most likely implement a more diverse fuel and propulsion spectrum than today.

For instance, e-Methanol is predestined for large passenger ships like ferries and cruise ships, and it can also be easily used in inland waterways. Methanol-driven ships are already in use, for example the “Stena-Germanica” ferry since 2015 and the methanol-fueled transportation fleet operated by Methanex. An important advantage of methanol over LNG is that there is no climate-damaging methane slip from the reciprocating engine’s operation. In addition to combustion engines fuel cells, that run on methanol (direct methanol fuel cell, DMFC) are under development. They could be used for applications like feeding electrical drives and generating power and heat for on-board facilities of cruise ships.

For large-scale bulk ships operated by small, highly trained crews, e-Ammonia is being intensively discussed as a CO_2-free fuel for ship operation. e-Ammonia is produced from green hydrogen and nitrogen using the established Haber-Bosch process. The broad introduction of e-Ammonia – similar to e-Methanol – would be able to use an established infrastructure for distribution and application. A white paper is available from Siemens Energy that addresses e-Ammonia.

Aviation

Aviation accounts for 2.4 percent of global CO_2 emissions (918 Mt CO_2 in 2018). In addition to improvements in propulsion efficiency (1.5 percent/a between 2009 and 2016), the potential future application of batteries for short distance flights, and using bio-kerosene, it will be necessary to deploy synthetic e-fuels to meet the increasing fuel demand and simultaneously significantly reduce CO_2 emissions. High quality synthetic e-Kerosene also reduces the emission of dust; it can be directly applied without complex and expensive retrofits. Hydrogen is different: it requires special tank systems, intensive testing and approvals, and may face acceptance issues. Similar to land transportation, hydrogen requires a modified supply chain and infrastructure.

There are no obligatory CO_2 reduction targets, comparable to the European regulations on land transport, that are addressed in the Renewable Energy Directive (RED). Nevertheless, the Air Transport Action Group (ATAG) and International Air Transportation Association (IATA) have committed to the effort by releasing a target of a 50 percent reduction in net aviation CO_2 emissions by 2050 (Figure 13). A more stringent commitment published in September 2020 by the “oneworld” association that unifies 13 airlines and about 20 of their affiliates in an effort to approach net-zero carbon emissions by 2050.

The aviation industry introduced their own category of CO_2-neutral fuels - Sustainable Aviation Fuels (SAF) - which can be either produced from biomass, waste or using of renewable electrical energy to produce Powerfuels. These are projected to become the best option for implementing RES in the aviation sector. However, until now, the aviation industry views Powerfuels only as a long-term solution.

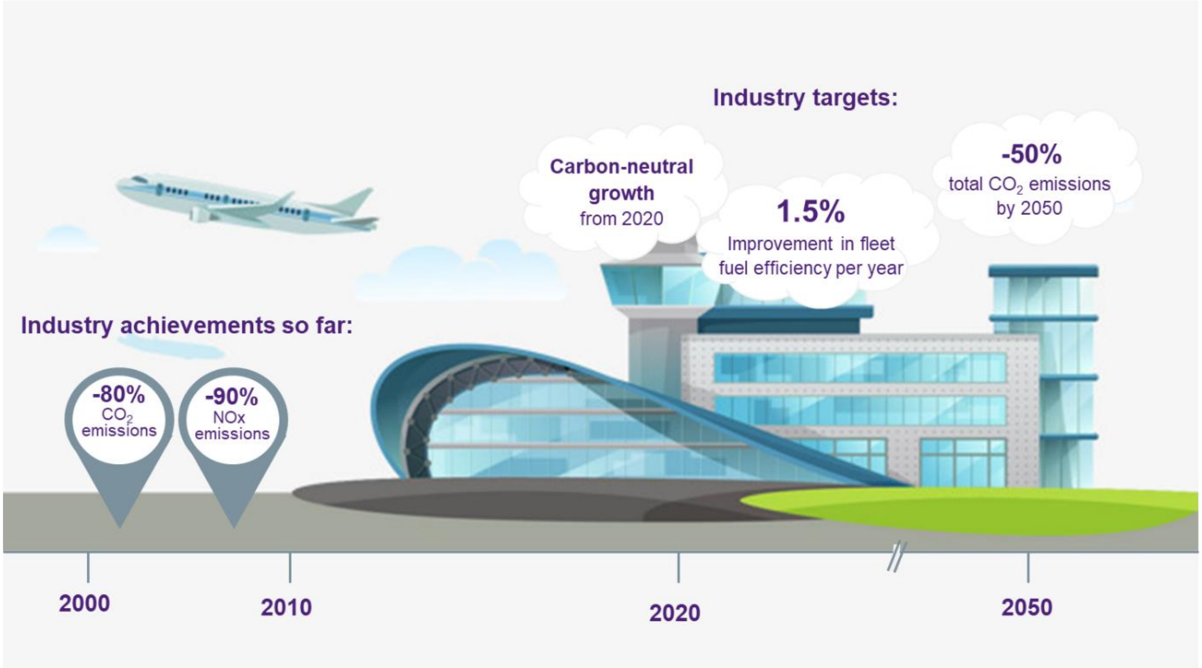


Figure 13: CO2 emissions reduction targets for the aviation sector (Source: based on Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

Similar to e-Gasoline, e-Kerosene can be synthesized via two routes, the Fischer-Tropsch process that includes a refining stage and the more selective MtK process, which is not yet commercially available, and will be implemented in demonstration projects. Both pathways have achieved comparable technology-readiness levels.

The MtK process is quite similar to MtG. It must be modified to produce the C_9-C_{14} chain hydrocarbons, typical of jet fuel. The first R&D projects, for example KEROSyN100, are under development, while Fischer-Tropsch kerosene from biogas has been already certified for 50 percent blending with conventional jet fuel.

4 Roadmap for implementing e-Methanol

Pilot and demonstration plants

As shown in Figure 14, there are very few plants worldwide for producing of renewable methanol, an most of them are producing bio-methanol from biomass/waste. Only one commercial plant in Iceland uses green Hydrogen from water electrolysis and CO_2 taken from local geological sources. At 4 kt/yr, its production capacity is quite limited. The small-scale plant has been continuously operated since 2012 and has proven its technological maturity. e-Methanol produced on the island is marketed through various channels in continental Europe. There are plans to expand the plant’s production capacity, but no final investment decisions have been made.

In the context of the BMWi funded E2Fuels project Siemens Energy is working with the Stadtwerke Hassfurt, MAN Energy and academia to pursue the development of the novel PtMethanol concept, which should become more efficient and operationally flexible, fulfilling the needs from volatile RES. The results of lab-scale tests of the synthesis concept will be implemented in a pilot project. The first production of e-Methanol is expected in 2021.

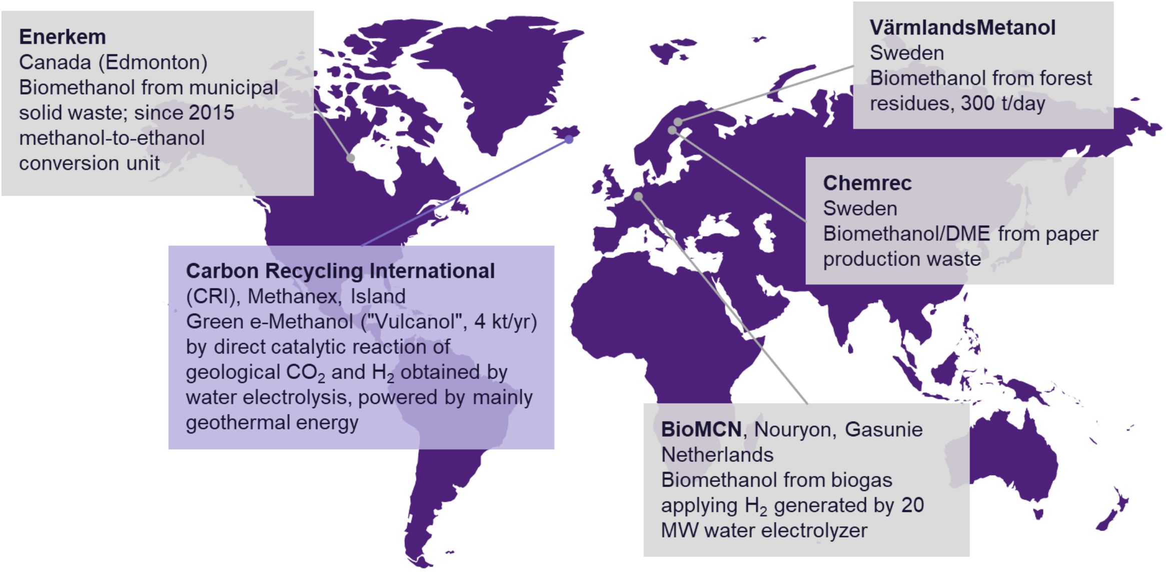


Figure 14: The first projects for renewable methanol production are already in operation

Large-scale production

It is clear, that in parallel to small-scale demonstration plants, scalability and maturity in large-scale plant operation have to be achieved quickly. Only fast development coupled with lowering the investment risk and construction costs can help to build up required production capacity. Figure 15 gives an example of estimated balance data for a PtMethanol plant, which will be constructed in Chile. This project, launched in December 2020, will demonstrate an interaction of all essential plant components, as well as create a basis for scaling up large size plants, in range of many hundreds MW. These plants, usually located in regions with a high production potential and low cost, green electricity, are dedicated for production of green hydrogen, w/o use of grid electricity. Nevertheless, in regions with weak grid infrastructure, PtL plants could be connected to the grid, stabilize and improve its reliability.

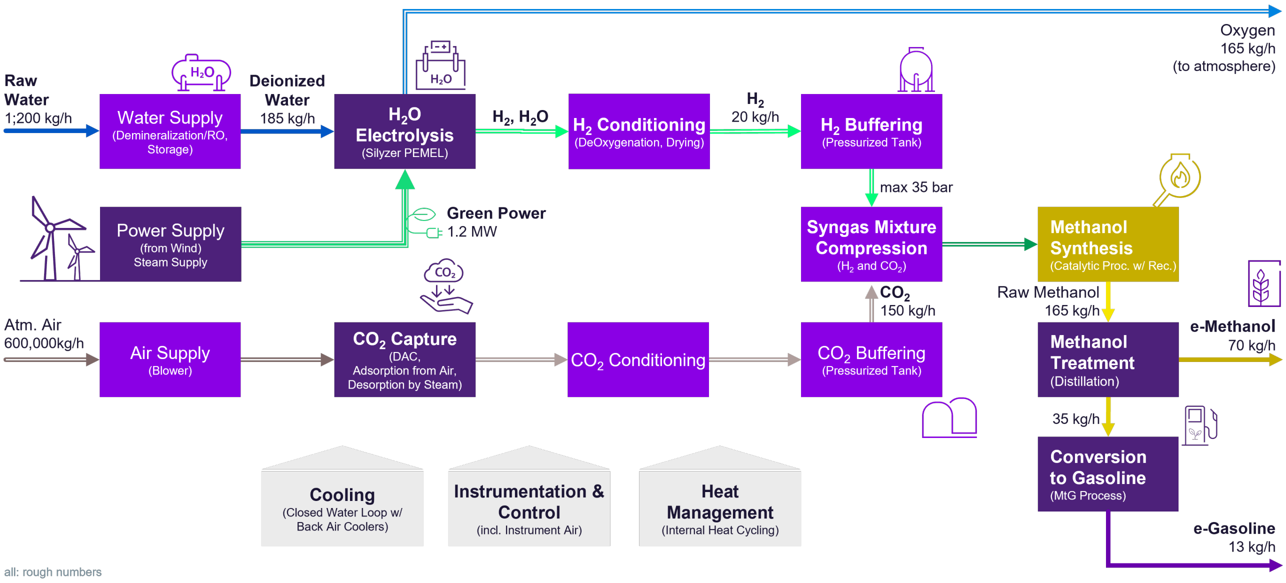


Figure 15: Simplified process flow diagram and mass balance for an exemplary Power-to-Methanol plant

PtL plants can be designed using modular concepts with single train electrolysis capacities of up to 200 MW_{el}. Highly standardized process units for example, the electrolysis systems, economies-of-scale for the chemical syntheses and pre-manufactured components will help reduce investment costs and shorten the construction time.

Nonetheless, large-size and complex PtL-projects require extensive experience in project development, financing and execution. During the introduction phase over coming years, risk sharing, close partnerships, governmental support and last not at least: public acceptance can speed up evolvement it this well promising technology, and positively impact the reduction of net CO2 emissions.

In close collaboration with customers and partners Siemens Energy is currently developing its first PtL projects, by drawing on the company’s technology expertise, its products, flexible PEM (Polymer Electrolyte Membrane) electrolysis, and its extensive solution and project management experience. The first pre-commercial Haru Oni project will be realized in Patagonia Province in Chile, fig.15, 16.

Figure 16: Haru-Oni pilot plant, Patagonia, Chile

The Haru Oni project will be the first commercial industrial-scale plant for production of climate-neutral e-fuels. Production capacities of e-fuels are planned to reach 130,000 litres during the pilot plant operation by 2022, 55 million litres for the first phase of commercial plant by 2024 and up to 550 million litres in the following phase. The “Haru Oni” pilot project takes advantage of the excellent wind conditions in southern Chile to produce carbon-neutral fuel using wind power. Final products will be e-methanol and e-gasoline, produced from methanol via methanol-to-gasoline process. The project is supported through funding by the German government under the National Hydrogen Strategy program. Siemens Energy has developed the Haru Oni project with partners such as HIF, Porsche AG, and Chilean ENAP. The project will demonstrate the Siemens Energy’s PEM electrolysis technology in an industrial scale.

Siemens Energy has recognized the value of PtX-solutions for the decarbonization of multiple industries many years ago. The company is preparing to provide a full range of customized solutions for each application, beginning with production of electricity from wind, offering of green hydrogen and e-fuels production or ending with carbon-free re-electrification. All of these stages will be available on a component, as well as on a turnkey basis (Figure 17, also see Siemens Energy’s white paper on Power-to-X).

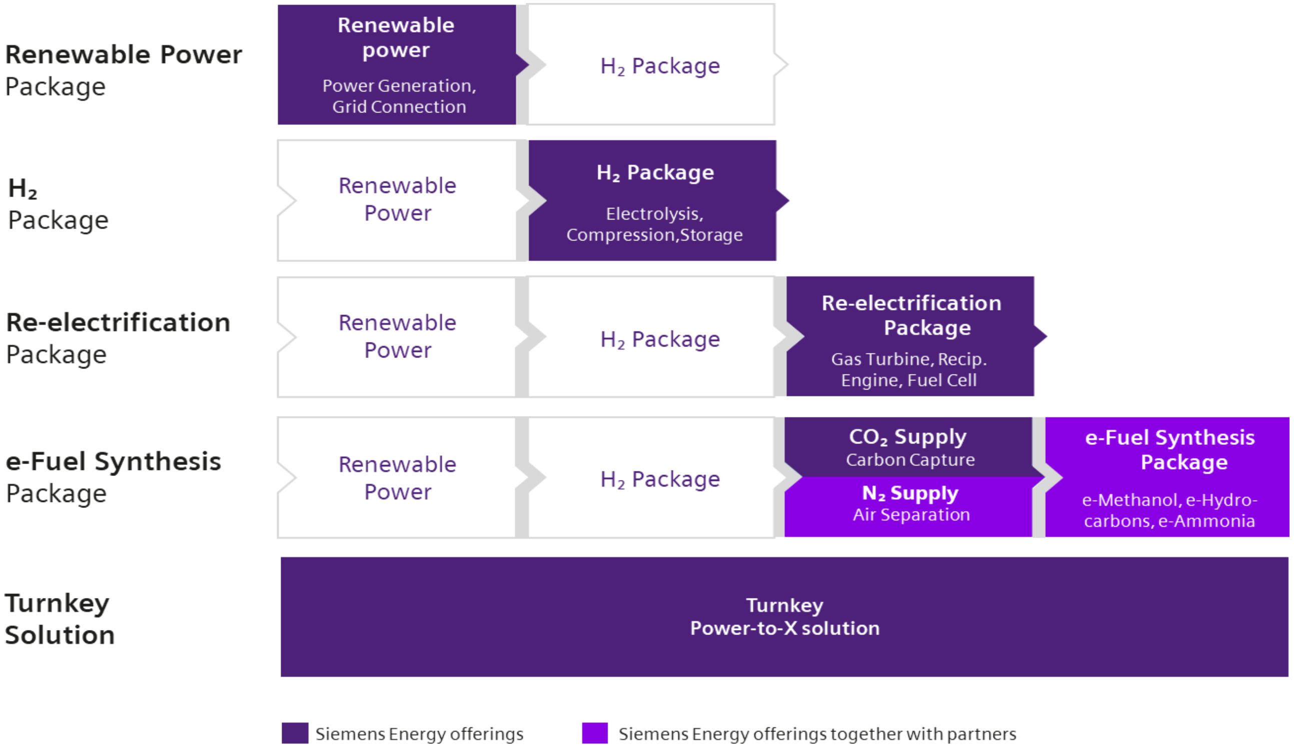


Figure 17: Siemens Energy's modular approach to Power-to-X plants.

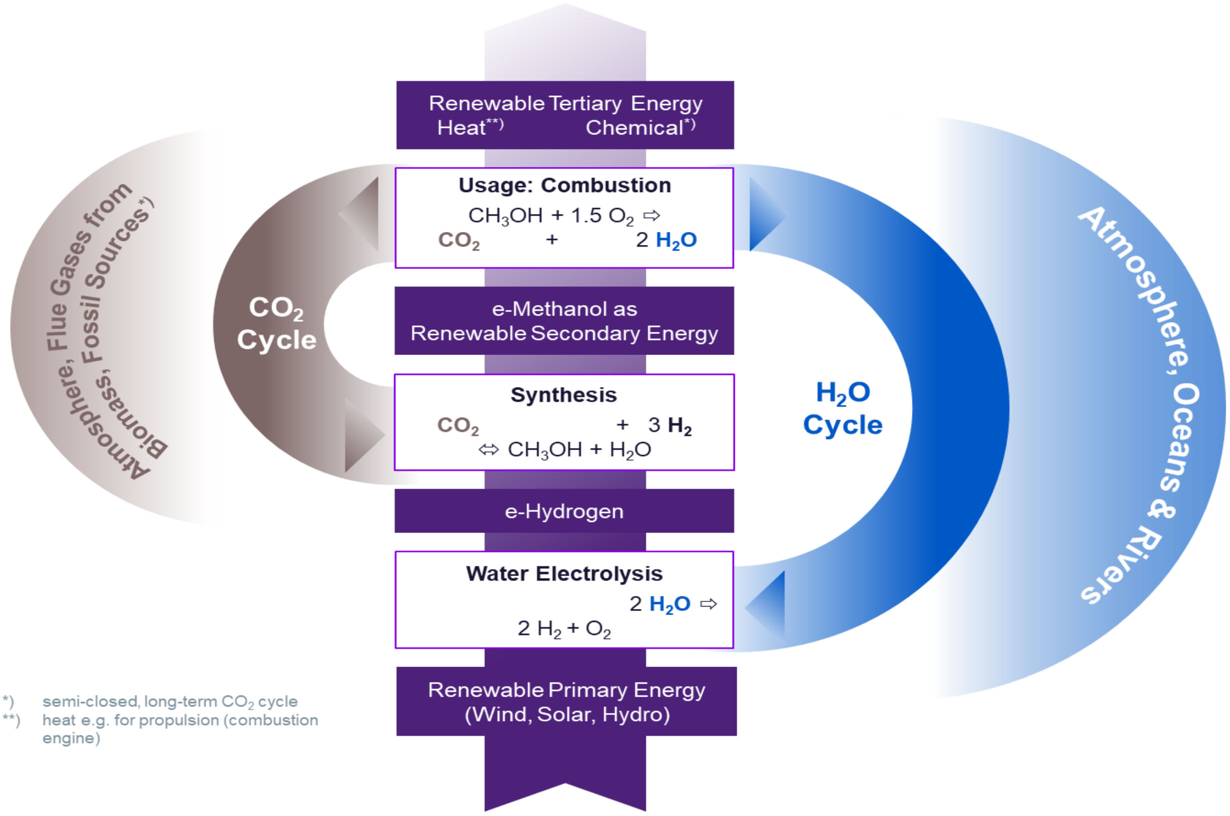
Using well proven plant components, known from the electricity production, transformation and distribution, having extensive experience in serving the oil & gas industry, as well as developing own key-PEM electrolysis-technology, in partnerships with global e-fuel synthesis technology leaders, Siemens Energy is well prepared to deliver any kind of solution with benefit for the climate protection and customers satisfaction.

5 An e-Methanol economy – Vision or fantasy?

Methanol is a universal chemical compound. It can be easily synthesized from materials containing carbon (CO, CO_2) and H2. And it can be used as an energy carrier or to produce other fuels as well as a basic feedstock for numerous chemical products.

In the 1990s the Nobel laureate chemist George A. Olah was already promoting the introduction of a so-called methanol economy which, however, has did not enjoy a positive response from industry and politics at the time. However, with the need to decarbonize our existing energy consumption patterns and drastically decreasing the cost of electrical energy from RES, his idea of establishing a methanol economy is being seen completely new light. Olah’s idea of a closed CO_2 balance via e-Methanol may very well become a reality for economic and environmental reasons (Figure 18).

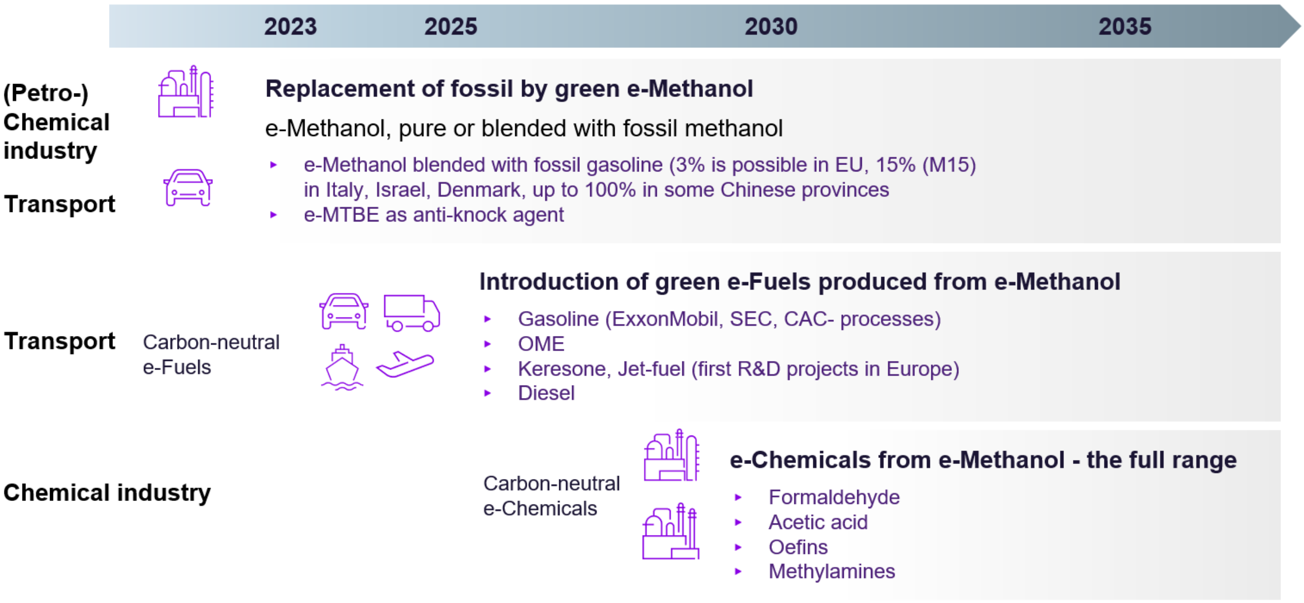
In principle, the transition to a green e-Methanol economy and the installation of e-Methanol hubs would be fairly simple: green hydrogen is produced at RES rich locations, converted into an energy-dense, liquid fuel (methanol), stored and distributed using established infrastructures, and used in different applications. This is how e-Methanol can integrate RES all over the world in the existing infrastructures of the transport sector, the chemical industry, and heating and decentral power supply systems. The concept becomes even more sustainable if the auxiliary energy - for example, for water treatment and CO_2 capture and logistics - comes from green sources. Many areas and their populations all over the world would profit by becoming players in an e-Methanol economy – including deserts with no resources to produce green energy from biomass, windy regions with no or low industrial development, and oil-exporting countries that are looking for new business opportunities. Regions that were left behind during earlier industrialization would be able to create a sustainable, autonomous and successful future.



*) semi-closed, long-term CO_2 cycle
**) heat e.g. for propulsion (combustion engine)

Figure 18: The concept of a sustainable e-Methanol economy

Countries like Germany will not be able to achieve an energy transition that is based entirely on local RES. As with fossil fuels, the need to import energy will persist in an e-Methanol economy. Applications in the transport sector could pioneer the introduction of e-fuels. Figure 19 shows a roadmap of the different application fields and implementation steps for e-Methanol and carbon-based e-fuels in general.



(Petro-) Chemical industry

Transport

Replacement of fossil by green e-Methanol

e-Methanol, pure or blended with fossil methanol

- e-Methanol blended with fossil gasoline (3% is possible in EU, 15% (M15) in Italy, Israel, Denmark, up to 100% in some Chinese provinces
- e-MTBE as anti-knock agent

Transport Carbon-neutral e-Fuels

Introduction of green e-Fuels produced from e-Methanol

- Gasoline (ExxonMobil, SEC, CAC- processes)
- OME
- Keresone, Jet-fuel (first R&D projects in Europe)
- Diesel

Chemical industry Carbon-neutral e-Chemicals

e-Chemicals from e-Methanol - the full range

- Formaldehyde
- Acetic acid
- Oefins
- Methylamines

MTBE: Methyl-tert-butyl-ether, OME: Oxy-methylen-ether

Figure 19: Scenario for evolvement of the green e-Methanol economy

The technologies needed to realize PtX are ready for scale-up in principle, and the concepts necessary to create large-scale PtL plants already exist. Investors are becoming increasingly interested in these new green opportunities, and e-fuel off-takers are recognizing the opportunity to reduce their carbon footprint in a sustainable way. If adequately promoted by policy – in other words, supported by regulations and incentives during introduction - and stimulated by the public’s interest the transition to an e-Methanol economy is likely to succeed.

Impressum

www.siemens-energy.com/hydrogen

Published by
Siemens Energy Global GmbH & Co. KG
Otto-Hahn-Ring 6
81739 Munich, Germany

For more information, please contact: support.energy@siemens-energy.com

Authors: Dr. Peter Kluesener, Dr. Ireneusz Pyc, Dr. Gerhard Zimmermann

Graphics: Siemens Energy

Siemens Energy is one of the world’s leading energy technology companies. The company works with its customers and partners on energy systems for the future, thus supporting the transition to a more sustainable world. With its portfolio of products, solutions and services, Siemens Energy covers almost the entire energy value chain – from power generation and transmission to storage. The portfolio includes conventional and renewable energy technology, such as gas and steam turbines, hybrid power plants operated with hydrogen, and power generators and transformers. More than 50 percent of the portfolio has already been decarbonized. A majority stake in the listed company Siemens Gamesa Renewable Energy (SGRE) makes Siemens Energy a global market leader for renewable energies. An estimated one-sixth of the electricity generated worldwide is based on technologies from Siemens Energy. Siemens Energy employs more than 90,000 people worldwide in more than 90 countries and generated revenue of around €27.5 billion in fiscal year 2020.
www.siemens-energy.com

Disclaimer