Green methanol: The basis for a CO_2-neutral circular economy

Siemens Energy and Liquid Wind partnering up to use renewable energy and industrial CO_2 as raw material for applications in mobility and industry.

Methanol synthesis based on green hydrogen and CO_2 from biomass-based industrial flue gas raises the prospect of a carbon-neutral industrial system. As a fuel for mobility applications and feedstock for the chemical industry, green methanol can decisively drive the defossilization of industry sectors. At the same time, integrating methanol production into existing industrial facilities such as combined heat and power plants or pulp and paper mills, creates a local and CO_2-neutral closed-loop system.

Today, methanol is one of the most widely produced organic chemicals and one of the most important raw materials in the chemical industry. As an energy carrier, methanol can be used in various industries and by end consumers as a fuel for mobility applications or used to generate energy in fuel cells ("Direct Methanol Fuel Cell" or "DMFC"). Since conventional methanol production from natural gas releases significant amounts of fossil greenhouse gases, the carbon-neutral production of green methanol on an industrial scale can make an important contribution to the energy transition.

In particular, eMethanol can play an important role as an energy carrier. eMethanol can help to reduce emissions during the transition to electric mobility options, for the operation of vehicles for example. In the long term, even more countries will seek to limit or ban internal combustion engines to meet climate targets. First national plans aim for banning the registration of new vehicles with diesel and gasoline engines from 2030. eMethanol provides the option of carbon-neutral mobility, as it can be blended with gasoline and can be used in this form in any engine – in China, for example, methanol is already being added to gasoline as standard. With Direct Methanol Fuel Cells, it is also possible to run electric vehicles of any type entirely on methanol.

Production from water, green electricity, and industrial waste gases

eMethanol is produced by chemically combining CO_2 and hydrogen. First, hydrogen is produced in an electrolyzer. The hydrogen is converted into methanol in a reactor by catalysis with carbon dioxide (CO_2). To produce 'green' (i.e. carbon-neutral) eMethanol, hydrogen from renewable electricity is used in combination with biogenic CO_2.

The potential of this method lies in the fact that the CO_2 used can be obtained via carbon-capture processes, for example from industrial waste gases (biogenic or non-biogenic CO_2), or captured directly from the air ("Direct Air Capture" or "DAC"). This process both avoids the emission of further, climate-damaging carbon dioxide, and uses it as a resource and raw material for a new energy carrier. Based on proven technologies, eMethanol can therefore support sustainable industry, enabling CO_2-reduced production and supply chains, and even CO_2 neutral eMethanol, in case biogenic CO_2 and renewable electricity is used.

In addition, methanol synthesis produces water and waste heat, which in turn can be used within a closed-loop system. The water is fed back directly into the electrolysis process, where it serves as feedstock for further hydrogen production. The waste heat can also be captured and fed back into the overall system. The O_2 generated in the Electrolyzer can be used in additional industry processes, e.g. in the pulp mills for the bleaching process, wastewater treatment or efficiency increase of other processes.

Modelled on nature: photosynthesis

eMethanol synthesis from green hydrogen and CO_2 uses the model of photosynthesis in green plants, which uses the energy of sunlight to split water into oxygen and hydrogen. While the oxygen is being released, the plants absorb carbon dioxide from the air and combine it with hydrogen to produce storable fuels such as sugar and polyalcohol.

Using the same principle, oxygen and hydrogen can be produced in industry from water and renewable electricity. The oxygen is released or used elsewhere – in medical applications, for example – while hydrogen and carbon dioxide are combined to form eMethanol.

Production on an industrial scale

Against the background of energy transition and national/international climate targets, a worldwide, concentrated expansion of capacities for renewable energy is not only to be expected, but essential. Efficient solutions that store renewable energy seasonally in large quantities are vital, given the natural fluctuations in the production of wind and solar power.

The production of eMethanol on an industrial scale offers a promising and economical solution to this challenge. Electrolysis from sustainable electricity sources produces hydrogen, which is converted into methanol by reaction with carbon dioxide. Like gasoline or diesel, the liquid eMethanol is comparatively easy to store, transport and use.

The first pilot plants for this purpose, particularly in Iceland, have now been in operation for almost 10 years.

Proven "Power to X" portfolio from Siemens Energy

The technologies required for all process steps in the industrial production of eMethanol are already available and well-proven. In recent years, Siemens Energy has been developing customized "Power to X" solutions for the de-carbonization of various industries and established partnerships with the world's leading suppliers of e-fuel synthesis technologies. From wind power, green hydrogen and e-fuels production to carbon-free re-electrification, Siemens Energy benefits from many years of experience in the oil and gas industry, so that most of the relevant plant components have been available, proven in use and established for years. With the "Proton Exchange Membrane" (PEM) electrolysis, Siemens Energy is a leading supplier for the most promising Electrolyzer technology for sustainable hydrogen production. This PEM-technology, in comparison to the classical Alkaline Technology, matches perfectly to cope with the high volatile sustainability on the market for renewable electricity and just needs power and water and no additional (toxic) chemicals for the production of green hydrogen.

Global roll-out of a model project

Swedish Power-to-X company Liquid Wind is currently planning the first large-scale industrial roll-out of eMethanol production facilities across Sweden in partnership with pulp and paper mills and CHP plants. Liquid Wind is also planning to develop Flagship facilities in Europe and other suitable locations internationally. The Flagship facility will use Siemens Energy's Electrolyzer of the newest generation, Silyzer300, which is highly adaptive and matching the requirements of the specific value chains. The eMethanol produced can be used to power ships and replace marine fuel oil. Ten Flagship projects with an annual production volume of 50,000 metric tons of eMethanol each are to be built by 2030. The company is planning to scale rapidly and has a vision to develop 500 standardized plants worldwide by 2050.
This scaling is made possible by the consistent use of digital capabilities. The entire planning and integration are carried out with the help of licensing via a Digital Twin for data (COMOS), process and operations, which is also provided by the Siemens Ecosystem. This means that the plants worldwide can be planned, tested, and efficiently operated via Digital Twin implementations. On this basis, there are great development opportunities for scaling up in countries that are rich in renewable energy and – with the synthesis from hydrogen and CO_2 – can both meet growing demand for green methanol.

Closed production cycles

In the first Flagship project, Liquid Wind will co-locate the eMethanol plant with a combined heat and power plant

(CHP) from Övik Energy in Örnsköldsvik/Sweden to make use of biogenic CO_2, renewable electricity from additional wind power and other utilities. The biomass-based flue gases will form the green raw material for carbon-neutral fuel. In the process, CO_2 for methanol synthesis is captured from the plant's biomass-based flue gas. The purified water is used for hydrogen electrolysis, as is the water produced as a by-product during methanol synthesis. The waste heat is used to supply energy to the local district heating and to concentrate the CO_2. For future facilities, the pulp and paper industry is an ideal industry partner for eMethanol production, the oxygen produced can be returned to the pulp mill or CHP. Additionally, mills could use the eMethanol produced to replace diesel used for trucks, fork lifts/lift trucks or caterpillars in their distribution chain to further reduce CO_2 emissions.

Each Liquid Wind facility will produce 50,000 tons of eMethanol per year. To achieve this, 75 MW of renewable electricity from wind power will be used to produce green hydrogen, and 70,000 tons of biogenic CO_2 will be upcycled. Four Siemens Silyzer300 units will be used as Electrolyzers for hydrogen production. Siemens Energy is also responsible for plant-wide electrification, instrumentation & automation, including engineering and services, as well as digitalization with Digital Twin implementation, Industrial Internet of Things (IIoT), analytics and AI applications. Production from the first flagship project in Örnsköldsvik, Sweden is scheduled to start early 2024.

Green alternative for marine propulsion and industry

eMethanol offers a sustainable fuel option, especially for ship propulsion systems that are predominantly operated using 'marine diesel' (heavy fuel oil). Due to marine diesel's poor ecological assessment and significant fossil carbon emissions, its use cannot be reconciled with international climate targets. Worldwide, marine diesel fueled ships are already refused entry to many ports, while countries like Norway aim at bans in coastal waters. Some shipping companies are therefore switching to liquified natural gas-driven engines (LNG), to reduce sulfur emissions, even though they are not carbon-neutral. Due to its compatibility with existing infrastructure, eMethanol offers a viable alternative to reach climate targets and significantly reduce fossil carbon emissions.

Of the approximately 98 million metric tons of methanol produced worldwide each year, around 85% is used as a feedstock in the chemical industry for syntheses or as a solvent. Countries like Taiwan, which themselves lack the fossil fuels for methanol production, import large quantities of methanol for their chemical industry. At the same time, those countries with few raw materials are investing heavily in renewable energy such as photovoltaics and wind power. The synthesis of methanol based on hydrogen and CO_2 offers these countries the opportunity to substitute the demand for their own industry.

Fair competition needs fair conditions

The integration of eMethanol production can already be made economically profitable in many industrial areas. Furthermore, all technologies are available at the required scale and have been proven over many years, as the Siemens Energy portfolio confirms: from technical applications to the complete digital toolset. Research and development costs are therefore limited to optimizing existing technologies, achieving an even higher level of integrated operations and maximizing the use of Digitalization tools.

The widespread success of eMethanol as a raw material and energy carrier essentially depends on whether it can be offered at competitive market conditions. Above all, this requires appropriate legal and fiscal framework conditions for carbon-neutral methanol. To date, synthetic fuels have generally been more expensive for the consumer than fossil or oil-based energy sources and fuels. Fossil fuels are subsidized to a large extent by subsidies and tax breaks. For example, the environmentally harmful marine diesel is not subject to CO_2 tax and can be used tax-free in accordance with Section 27 of the German Energy Tax Act (EnergieStG).

To make lower-carbon and zero-carbon alternatives attractive and help the corresponding technologies achieve a breakthrough, economic incentives and tax relief are needed, as the example of successful wind power subsidies shows.

Solutions to climate policy challenges

In the short and medium term, the production of eMethanol from renewable electricity offers the opportunity to establish new, largely carbon-neutral economic cycles. In the long term, the conversion of renewable electricity into eMethanol – hand in hand with other application-specific technologies such as hydrogen and an expansion of power grids – raises the prospect of an energy economy that is no longer dependent on fossil fuels. This circular fuel generation will avoid further increase in greenhouse gases by ensuring that fossil resources remain in the ground.

A methanol economy based on renewable electricity therefore provides the solution to many climate challenges, which although already addressed in some way today, require a better conceived and integrated approach.

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