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Power-to-Methane

Seasonal energy carrier – Power-to-X technology

Methane is a critical energy carrier with diverse applications across multiple sectors. As a primary component of fossil-derived natural gas, it supplies heat, electricity, and fuel for a wide range of industrial processes. In addition, methane is a versatile chemical feedstock, essential for producing hydrogen, ammonia, and various petrochemicals.

Traditionally, methane supply has relied heavily on fossil fuel extraction through natural gas production and conventional methods. However, renewable methane production offers sustainable alternatives through two primary pathways: bio-methane production and Power-to-Methane ($PtCH_4$) processes. Biomethane production involves converting biomass into biogas through anaerobic digestion, followed by CO_2 removal to obtain pure methane. This method is already widespread but faces limitations due to biomass availability. Switzerland still has untapped biomass resources that could be utilized for energy purposes [6]. The biomass with the greatest additional usable potential is farmyard manure with 24 PJ (equivalent to 6.67 TWh) of primary energy, which could be used for biomethane production.

The $PtCH_4$ production relies on hydrogen production through water electrolysis, which then reacts with CO or CO_2 in a methanation reactor to form synthetic methane (SNG, Figure 1).

The process follows the Sabatier reaction:
$4\,H_2O + CO_2 \leftrightarrow \;\; CH_4 + 2\,H_2O + 2\,O_2$.

This methanation process can be achieved through a) catalytic methanation, which uses chemical catalysts (typically nickel-based) at high temperatures (300 to 400°C) and pressures to convert CO_2 and hydrogen into methane.

This method offers high conversion rates and rapid reaction kinetics b) biological methanation, which, unlike biomass-based biogas production, uses methanogenic microorganisms (archaea) to convert externally supplied CO_2 and hydrogen into methane at lower temperatures and pressures, mimicking natural biogas production processes.

While biological methanation operates under milder conditions and can be more flexible in handling varying feed compositions, it typically requires longer reaction times compared to catalytic processes.

If this methanol is burned, the same amount of CO_2 is released as was used in its production for synthesis. If the used CO_2 is taken from Direct Air Capture (DAC) or from renewable exhaust gases (CO_2 from biogas), the carbon cycle is thus closed the process chain is carbon neutral.

In Switzerland, the first industrial-scale $PtCH_4$ facility using biological methanation has been operating since March 2022 at Limeco in Dietikon. Globally, the world´s largest $PtCH_4$ plant has been in operation in Werlte, Germany, since 2013 [4]. However, the production of $PtCH_4$ is still in its infancy but is being expanded, e.g., in Japan.

For large-scale applications, key challenges include the high energy demand of the production process, cost disadvantages compared to conventional natural gas, and the requirement for reliable CO_2 sources to sustain methanation.

Technology readiness: $PtCH_4$ is currently at an early commercial stage. Catalytic methanation is well established, whereas biological methanation is less mature. Electrolysers (alkaline and PEM) are commercially available, while the TRL of CO_2 capture technologies varies depending on the source of CO_2.

The overall efficiency of $PtCH_4$ processes is in the range of 35–60% (LHV-based), with electrolysis efficiencies of 50–70% for PEM, 56–61% for alkaline, and 70–80% for SOEC, while methanation efficiencies lie between 70–85% [2,4,7]. Methane can be stored either as compressed gas in pressure vessels or as liquefied synthetic gas (SNG), which is obtained by cooling methane to –162 °C. For transport, gaseous methane is typically distributed via pipelines, whereas liquefied methane can be shipped by sea, rail, or truck.

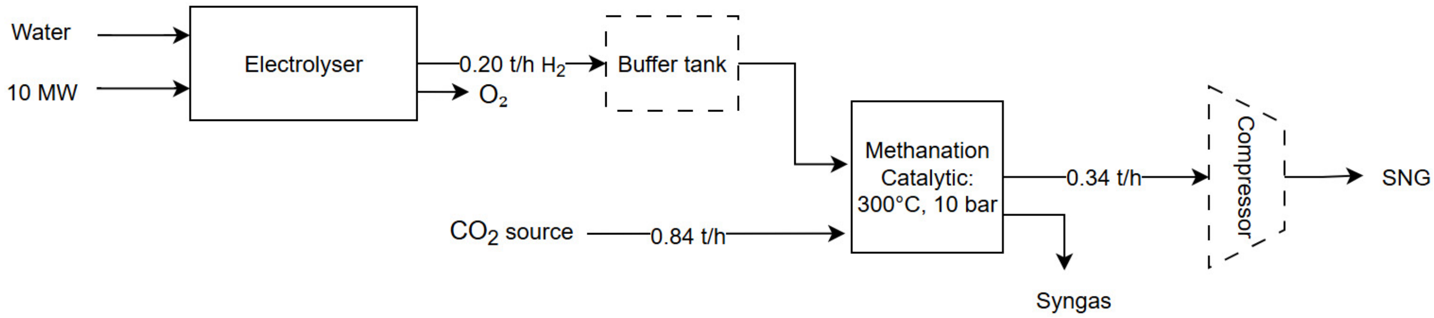


Figure 1: $PtCH_4$ (SNG) synthesis process flow diagram for a 10 MW electrolyser. Dashed units are the ones that can be installed but are not necessary. The CO_2 can come from different sources and can be extracted in different ways.

Availability

Global production of $PtCH_4$	116 MWe of installed electrolysers [8]
Swiss production of $PtCH_4$	6 PJ (5.5% of consumption with 1.4% being biomethane) [5] 3.35 MWe of installed electrolysers [8]
CO_2 source	biogas production, waste incineration, wastewater treatment, direct air capture

Chemical properties & Safety

Volumetric energy density (LHV): Net calorific value	9.94 kWh/m_3 @standard conditions: 273.15 K, 1.013 bar
Gravimetric energy density: Net calorific value	13.9 kWh/kg
Melting point / boiling point	-182 / -161 °C
Flash point / Auto ignition	-188 °C / 537 °C
Explosive / flammability limits in air	Highly flammable (4.4-17%)
Health safety	Not toxic, but can cause severe skin burns and eye damage
Safety (hazard based on EU Regulation	H220, H280
Safety (precaution based on EU Regulation	P210, P377, P381, P403

PtCH4 installations in Switzerland

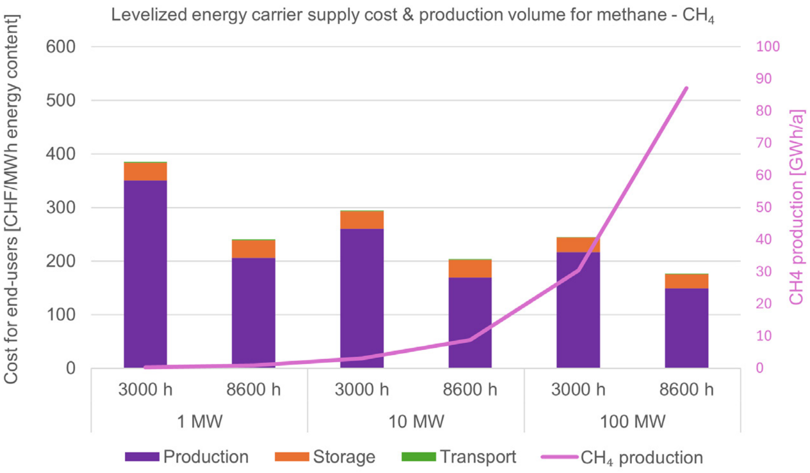
Limeco: Commercial $PtCH_4$ plant. It uses the renewable electricity of Limeco's waste incineration plant to produce hydrogen. Then it is mixed with sewage gas and converted into methane which can be fed into the natural gas grid. Capacity: 2.5 MW electrolysers. Location: Dietikon

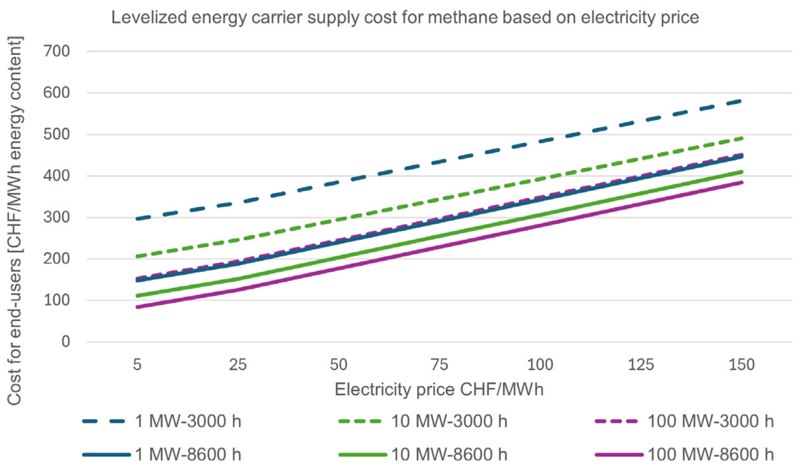
Gaznat: Testing of a methane reactor integrated into a $PtCH_4$ system. The synthetic methane is injected into the local distribution grid. Capacity:
11 kW SNG. Location: Sion.

Ostschweizer Fachhochschule: 1st $PtCH_4$ demonstration plant in Switzerland. Location: Rapperswil.

Cost analysis

The production costs take into account the hydrogen production and the methanation process. The costs were calculated for a PEM electrolyser; more information on the hydrogen costs can be found in the corresponding factsheet. A fixed cost on CO_2 with 0.05 CHF/kg has been applied, taking the average unit cost for different CO_2 sources and technologies.





For methane synthesis, the specific costs for each size were derived from different studies [1,3]. All assumptions and values can be found in the Sources/additional information section.

Three different sizes of electrolysers have been analysed, and for each, a half-year and a full year operation have been analyzed. The storage investment is based on a study where seasonal gas storage in caverns was analyzed [9]. The levelized cost of methane ranges from 145–210 CHF/MWh under full-year operation and 235–370 CHF/MWh under half-year operation, compared to 20–50 CHF/MWh for fossil-based fuels.

Sources / additional information

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