UPGRADE FOR BIOGAS PLANTS

The energy policies of any country are focused on solving their own energy problems – this includes Switzerland. Nevertheless, experiences from other countries can help identify suitable paths toward a renewable and efficient energy supply. A research project involving the Eastern Switzerland University of Applied Sciences (OST) examined how the bus fleet in Uppsala, Sweden, could be operated with additional locally produced biomethane. The results are also relevant for Switzerland's biomethane supply.

Since March 2022, the Limmattaler Regiowerk Limeco in Dietikon (ZH) has been operating Switzerland›s first industrial power-to-gas plant together with eight Swiss energy suppliers. The design and cost-effectiveness of such plants can be calculated using the simulation tool developed at the Eastern Switzerland University of Applied Sciences. Photo: Limeco

A technical report about the results of a research project in the field of grids, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine Aqua&Gas (issue November 2024).

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Biogas-powered bus in the Uppsala city center. Photo: Gamla Uppsala Buss

In Swiss cities, a widespread electrification of bus transport is currently underway – whether through the establishment of new trolleybus and tram lines, or the use of battery-operated buses with charging stations at depots or stops. The northern Swedish city of Uppsala is also aiming for carbon-free public transport. However, the situation in the city of 250,000 residents differs from that of Swiss cities: Uppsala's 400 city and regional buses predominantly run on biodiesel made from vegetable oil (around 240 buses) or biomethane (about 160 buses). There are also a handful of battery-operated buses. The operating company is working to replace the (imported) biodiesel with (locally produced) biogas.

Increased output from existing biogas plants

Additional biomethane can be generated by building new biogas plants. Another approach is to optimize existing plants. Biogas from conventional biogas plants consists of about 60% methane (CH_4), which is energetically useful, while the rest is mainly CO_2, which is currently separated from the raw biogas. However, this CO_2 can be energetically utilized by converting it into methane through the addition of renewable hydrogen, a process called methanation. This can increase the methane production of a biogas plant by around 60%. Since electricity is used to produce hydrogen, such a system is referred to as a power-to-gas plant.

A Swiss-Swedish research team has spent the last four years studying the technical and economic aspects of such a power-to-gas plant for Uppsala. The Swedish University of Agricultural Sciences (SLU) in Uppsala and – as a junior partner – the IET Institute for Energy Technology (Rapperswil) of the Eastern Switzerland University of Applied Sciences (OST) were involved. Financial support came from the Swedish Energy Agency (Stockholm) and the Swiss Federal Office of Energy as part of the cross-border research program "ERA-Net Smart Energy Systems." The project will be completed in November 2024.

Large-scale biomethane production

The Swedish waste management company Uppsala Vatten operates a large biogas plant, which mainly takes in food waste from the Uppsala region. The annual production of approximately 9.3 million normal cubic meters (Nm^3) of raw biogas, or the methane derived from it, covers around 70% of the fuel needs of the gas-powered bus fleet in the city and region of Uppsala. "The Swedish biogas plant is significantly larger than the plants in Switzerland. The technical and economic exploration of a power-to-gas plant is particularly interesting in this context because economies of scale are expected to lead to lower production costs for biomethane," says Matthias Frommelt, a researcher at IET.

So far, alkaline electrolysis has been used for the industrial production of hydrogen. However, for the construction of a power-to-gas plant, the Swiss-Swedish research team now recommends an electrolyzer with PEM technology (see text

Members of the Swiss-Swedish project team in front of the Uppsala Vatten biogas plant in Uppsala (Sweden). The biogas plant separates the CO_2 from the raw biogas to produce high-quality biogas with a methane content of almost 100 per cent. Photo: OST

Delivery of green waste for the biogas plant at Uppsala Vatten. Photo: OST

Gas buffer storage at the bus depot in Uppsala. Photo: OST

Uppsala Vatten also operates a plant that converts liquefied natural gas (LNG) and liquefied biogas (LBG) back into a gaseous aggregate state. Photo: OST

box p. 5). While it is currently more expensive, the researchers argue that it promises higher efficiency. Another technical issue involves the process used to extract CO_2 from the raw biogas so that it can then be converted into methane using hydrogen. In Uppsala, the so-called water scrubbing method is currently used. This method has the disadvantage that the CO_2 is not separated in a form pure enough for methanation. If methanation is to be used in Uppsala, CO_2 would need to be separated from the raw biogas using a different method. One option under discussion is amine scrubbing, in which CO_2 is chemically bound by an amine (an ammonia derivative) washing solution and separated from the raw biogas.

Technical solutions are available

The research team has no clear technological preference over whether carbon dioxide and hydrogen should be converted into methane catalytically (methanation) biologically (methanization). “So far, the catalytic process is more widely used, but biological methanization offers advantages in handling and is likely to be slightly cheaper,” says Frommelt.

A key focus of the research project was the economic evaluation of a possible power-to-gas plant for Uppsala. “Whether the biomethane produced by methanation is competitive with conventional biomethane depends mainly on the price of electricity used to produce hydrogen,” says IET researcher Boris Kunz. “Based on the average electricity price before the price increases brought on by the energy crisis, our biomethane is at least nearly as competitive.” Expressed in figures: only when the price of electricity is below 7.5 euro cents per kilowatt hour would the biomethane be competitive. The research team also demonstrated, using a self-developed simulation tool (see text box p. 4), that profitability cannot be improved by procuring and storing electricity, hydrogen, or CO_2 under favorable market conditions.

METHANATION

Various processes are available for the methanation of carbon dioxide (CO_2) and hydrogen (H_2) into methane (CH_4), some of which have been known for a long time. In catalytic methanation, the starting materials CO_2 and H_2 react with the support of a catalyst (for example, nickel) to form methane. Biological methanization does not require a catalyst. Here, microorganisms ensure the conversion of CO_2 and H_2 into methane (and water).

SIMULATION TOOL FOR POWER-TO-X PLANTS, ALSO IN SWITZERLAND

An important element of the research project presented in the main text is the simulation tool developed at the IET for Power-to-X plants, i.e. plants that convert renewable electricity into methane or other chemical energy carriers. The tool was used in the project to calculate the technical design and economic viability of a potential methanation plant in Uppsala. At the same time, the Swiss-Swedish project served to further develop the simulation tool, which had been created in recent years in collaboration with the company AlphaSYNT.

The software tool is typically used to simulate one year of operation of a Power-to-X plant in hourly resolution. All mass flows are simulated. So far, the tool can be applied to plants for the production of hydrogen, methane and methanol. Power-to-X plants are currently being scaled up. As there is still little experience with them, simulations provide important support in the design and enable economic efficiency calculations.

So far, the IET's simulation tool has not only served well in projects in Sweden and Ethiopia, but also in Switzerland. On behalf of Elektrizitätswerk Jona-Rapperswil AG and Energie Zürichsee-Linth AG, a potential study for a hydrogen filling station in the Rapperswil-Jona area was carried out. The facility would convert solar power into hydrogen, which could then be used to refuel fuel cell vehicles.

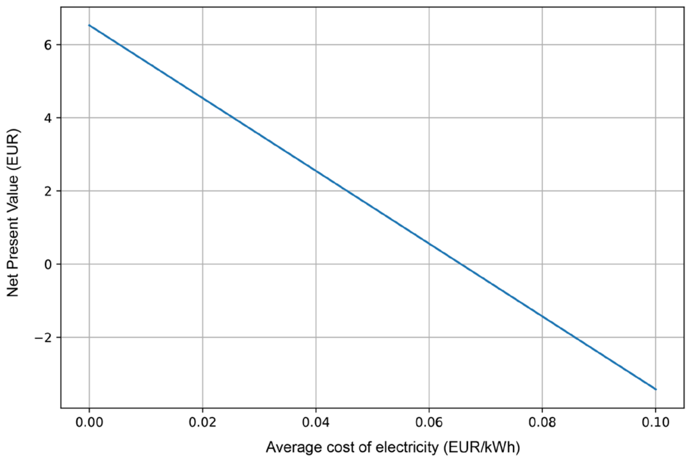
Ambivalent solar power

Uppsala Vatten operates a medium and a large photovoltaic system with a total capacity of almost 5,000 kW_p. According to the research team’s calculations, this solar power could cover about 10% of the electricity needs of the electrolyzer. However, the solar power cannot be used directly; it must be fed into the grid, which incurs a grid usage fee, making the electricity more expensive. This presents a dilemma: Using more solar power for the power-to-gas plant means using ‘green’ electricity, but it makes the produced biomethane more expensive. From an energy perspective, it would be more efficient to use the solar power directly in battery-powered buses. In a well-to-wheel analysis, an electric bus converts around 80% of the solar energy into propulsion, while a gas-powered bus converts only about 15%, due to conversion losses of electrolysis and methanation. Gas buses still play a key role in Uppsala’s transport system, because the network has grown over time. Furthermore, regional buses with long ranges cannot yet be easily electrified.

Whether the Swedish city will actually implement a power-to-gas plant was not decided by late summer 2024. While the additional biomethane would be welcome, the higher costs and the EU’s proposed ban on internal combustion engines pose challenges. Battery and hydrogen-operated buses are being discussed as alternatives.

First Swiss power-to-gas plant

In Switzerland, biomethane is likely to continue playing a minor role in the transport sector in the future. Nevertheless, additional quantities of this energy source are welcome to replace fossil methane (natural gas) in heating systems and in industry. As early as 2022, the regional utility Limeco in



The Net Present Value method is a method of calculating the profitability of a technology by discounting the investment costs and cash flows during operation term from the time of startup. If the capital value is above zero, the technology is economical, if the value is below zero, it is uneconomical. The sensitivity analysis of the OST researchers shows that the price of electricity is the biggest cost driver for this project. To be economically feasible, the price of electricity would have to be well below 0.10 EUR/kWh. Graphic: OST

Dietikon (ZH), together with eight Swiss energy suppliers, commissioned Switzerland›s first industrial power-to-gas plant. The plant's capacity is designed to produce around 1.8 million Nm³ of biomethane annually, which the participating energy suppliers sell to their customers through certificates. This avoids around 5,000 tons of CO_2 emissions per year, equivalent to the emissions from natural gas heating from about 2,000 households.

- Information on the **research project** "Energy storage for sustainable regional development: Optimized integration of renewables in smart transport systems" (Power-to-Transport) at: www.aramis.admin.ch/Texte/?ProjectID=47341.
- **Information** on the project is available from OST scientists Matthias Frommelt (matthias.frommelt@ost.ch) and Boris Kunz (boris.kunz@ost.ch).
- Further **specialist articles** on research, pilot, demonstration and flagship projects in the field of electricity can be found at www.bfe.admin.ch/ec-strom.

PEM ELECTROLYSIS

Electrolysis breaks down water into the chemical elements hydrogen and oxygen using electricity. PEM electrolysis is one of many electrolysis processes. It uses a proton-permeable polymer membrane (proton exchange membrane/PEM) to split the water. In this process, the water is first split into oxygen, free electrons and positively charged hydrogen ions. The hydrogen ions diffuse through the membrane and combine with free electrons on the other side to form hydrogen.

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