Biological Power-2-Gas - LIMECO

Biological Power-2-Gas production from waste and wastewater - a Swiss Flagship Project

Case Study

IEA Bioenergy: Task 37: 12 2024

Authors: Hajo Nägele, Wolfgang Merkle, Thomas Di Lorenzo, Niclas Gündel
Edited by: Jan Liebetrau, Jerry Murphy

Motivation and Business Model

Limeco (Dietikon/Switzerland) is an inter-municipal institution that has a 65-year record of provision of waste management services. It specialises in wastewater treatment, waste incineration, and district heating, for its eight member municipalities and various contracting municipalities (Table 1). In the past, up until 2015, the biogas from sewage sludge was utilized via combined heat and power (CHP) units.

Swisspower, is a strategic alliance of 21 Swiss municipal utilities, who have an ambition to provide a fully renewable, CO_2-free energy system by 2050. In 2016, Swisspower partnered with Limeco and Kanadevia Inova Schmack GmbH to build a biological Power-2-Gas (P2G) plant. The motivation behind this project was to harness synergies from existing facilities—including electricity generation, biogas, and sewage sludge treatment—to contribute flexible energy to a future-oriented CO_2-neutral energy system. This distinctive approach fosters innovative integration, whilst unlocking potential for a more cohesive and adaptable energy production model.

The Limeco site was ideal, as the wastewater treatment plant supplies sewage sludge and biogas, while electricity from the waste incineration plant is available at market prices for electrolysis, without grid fee. During the planning phase, additional co-operation partners were sought to support Limeco in the project. The developed business model envisions that the eight member municipalities will purchase biomethane at cost price for a period of 15 years. Following a planning and construction phase, the P2G plant became operational in March 2022. The total costs for planning, construction, and process engineering reached CHF 14 million, equivalent to about US$16 million.

Limeco's biological P2G plant is Switzerland's first industrial, full-scale P2G facility, representing a significant milestone in the energy transition. It can produce up to 18 GWh of energy annually (2MW renewable methane capacity) and reduces CO_2 emissions by up to 5,000 tonnes per year (or 277 kg CO_2/MWh renewable methane or 2.77 kg CO_2/m^3 renewable methane, or 277 g CO_2/kWh).

Table 1: Technical developments at LIMECO

Technology	Year	Input parameter	Treatment	Utilization
Wastewater Treatment	1967	135,000 Population equivalents (PE) 1 PE = 60 g BOD/d	3,200m^3 Primary Anaerobic Digester Vessel 2 x 1,200 m^3 post digester tanks	CHP, Membrane Upgrading, Flare
Waste Incineration	1971	90 to 95,000 t/a	Incineration	8 MW_e. turbine with steam condensation, which reduces to 2-3 MWe. in winter, as district heating is preferred
District Heating	2009	170 GWh/a which will be expanded	-	Heat supply for Households and Industry from Waste Incineration Plant
Biological Power 2 Gas	2022	Maximum of 90 m^3/h of CO_2 converted to 90 m^3/h methane, which is additional to 150 m^3 CH_4 from WWTP leading to total methane production of 240 m^3/h	Ex-situ CSTR biomethane reactor	18 GWh per annum biomethane max. Capacity Grid injection
CO_2-Membrane	2024	Biogas from WWTP	Upgrade to Biomethane	Grid injection

PROCESS CONFIGURATION

The wastewater treatment process in the Limmat Valley generates sewage sludge, which undergoes anaerobic digestion to produce biogas, with a production rate in the range of 140-250 m^3/h at 20 mbar. Limeco also generates electricity from the combustion heat at the waste incineration plant using a condensing turbine and a generator, with a maximum output capacity of 8 MW; this is reduced in the winter to 2-3 MW as the focus is on heat provision for district heating in the winter. The electricity powers the electrolysis system, splitting water molecules ($2H_2O$) into hydrogen ($2H_2$) and oxygen (O_2). It is important to note that, in Switzerland, only 50% of the electricity generated by a waste incineration plant qualifies as renewable. Consequently, only 50% of the electricity produced can be utilized for electrolysis, in compliance with renewable energy regulations.

The separate ex-situ biomethanation reactor uses a continuously stirred tank reactor (CSTR) with a capacity of 50 m^3 (equivalent to a mass of 30 tonnes of sewage sludge), operates at a pressure of 7 bar and a temperature of 65°C (Figure 1 and 2). It is designed for a maximum biogas production capacity of 90 m^3/h (at standard temperature and pressure (STP)) of CO_2 or 250 m^3/h sewage gas (STP). The initial microbial consortium is obtained from the secondary digester of the wastewater treatment plant (WWTP) and through feeding only with gases (CO_2, H_2 and CH_4) becomes dominated by hydrogenotrophic methanogenic archaea which are necessary for biological methanation ($4H_2 + CO_2 = CH_4 + 2H_2O$). The reactor features a central gassing agitator with a hollow shaft for efficient mixing. Gas is drawn from the headspace and reintroduced at the middle of the reactor. The system operates with a dry matter content of 2.5%.

Two electrolysers, each with a maximum installed capacity of 1.25 MW, are employed to produce hydrogen, generating up to 450 m^3 (STP) of hydrogen. The Power-to-Gas (P2G) plant requires 360 m^3/h of hydrogen (4 times the production of CO_2).

Due to the absence of storage, the hydrogen must be used immediately. Currently, the oxygen produced during electrolysis is released into the environment without technical utilization. However, there are plans to repurpose the oxygen either for use in the wastewater treatment plant or as secondary air in the waste incineration plant.

The hydrogen and biogas are pre-mixed and introduced into the lower section of the ex-situ biomethanation reactor. During the biomethanation process, water is produced, which dilutes the fermentation substrate; thus, a portion of the sludge must be regularly replaced. Each replacement includes the addition of nutrients and trace elements. The biological methanation system is designed to operate for 8,000 hours per year. The produced biomethane is scrubbed of trace gases (such as ammonia and H_2) and injected into the Dietikon gas grid at 5 bar pressure. Removal of hydrogen sulfide (H_2S) is done with activated carbon. A recent enhancement in the process involves gas treatment using a membrane (installation in February 2024) to separate residual CO_2 and H_2 from the biomethane. This membrane may operate as the complete biogas upgrading system, if the ex-situ biomethanation unit is offline. This addition, alongside the combined heat and power plant, emergency flare and biomethanation system, enables the treated gas to be processed and fed into the gas grid.

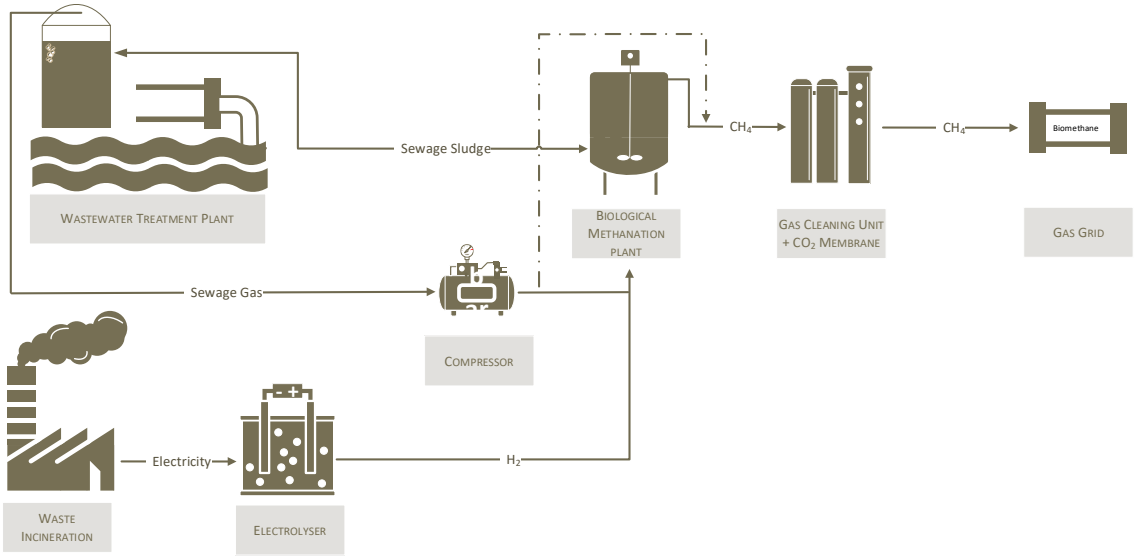

Figure 1: Simplified diagram of the process flow

The biomethane fed into the grid is distributed to the eight member municipalities, which then market their respective shares in their respective regions. Operational experience highlights that electricity prices are the key determinant of operating costs. With electricity prices as they were before the war in Ukraine, gas prices are comparable to conventional biomethane production.

OPERATIONAL INSIGHTS, EXPERIENCES AND CHALLENGES

The system was initially designed for standard operation at 8,000 hours per annum. Motivated by high energy prices due to the energy crisis, the system was expanded with the addition of the CO_2 membrane, which enables entire year operation.

To date, a "normal" operational year has not yet been realised. Due to a power shortage in the year 2022, the plant was non-operational from September 2022 through March 2023. Biological methanation demonstrates excellent performance; however, the target plant availability has not yet been attained, primarily due to issues related to plant construction.

A research project titled "Limeco Hybrid Power Plant: Power-to-Gas for Flexibilization of a Waste Incineration Plant," funded as a flagship initiative by the Swiss Federal Office of Energy (BfE), was conducted to explore the potential of flexibilization strategies. The findings from this project are detailed in a comprehensive project report, which can be accessed at: https://www.aramis.admin.ch/Texte/?ProjectID=47372.

FUTURE OUTLOOK

The construction of a new and expanded wastewater treatment plant (WWTP) will become necessary. Furthermore, the waste incineration plant reaches its end of life in 2034 and must be renewed. Based on this, Limeco has developed the vision of a “Multi-Energy Hub”. This vision involves continuing to utilize the existing core elements—Wastewater Treatment Plan, waste incineration, and district heating—and complementing them with new technologies such as P2G and energy storage systems to provide the Limmat Valley with heat, electricity, and gas. The system services provided aim to ensure a stable secure supply of energy (addressing winter gaps); and contribute to climate and energy transition goals. The operation of Limeco's P2G plant, currently the only commercially operational process of its kind in Switzerland, will determine whether P2G technology should be integrated into Limeco’s new plant concept. However, its continued operation and further development will depend on future market conditions.

As Power-to-Gas is a crucial technology for sector coupling—integrating electricity, gas, heat, and mobility within a sustainable energy system—the plant in Dietikon, Zurich, aims to advance and optimize the cost-effectiveness of Power-to-Gas technology in the Swiss energy landscape. In 2023, the power-to-gas pilot plant won the Watt d'Or 2023 prize, awarded by the Swiss Federal Office of Energy (SFOE).

Figure 2: Power 2 Gas demonstration site at LIMECO, Dietikon/Switzerland

Contacts

Limeco
Reservatstrasse 5
CH-8953 Dietikon
www.limeco.ch
www.powertogas.ch

Thomas Di Lorenzo
Thomas.DiLorenzo@limeco.ch

Niclas Gündel
niclas.guendel@limeco.ch

IEA Bioenergy
Technology Collaboration Programme

Further information on IEA Bioenery and IEA Bioenergy Task 37:

https://task37.ieabioenergy.com

www.ieabioenergy.com