Biogas methanation reactor

Kanadevia Inova AG (Inova) has developed a proprietary biogas (or CO_2) methanation reactor. The first example of the technology was brought to operation in 2022 in Gabersdorf (Austria). The technology allows converting H_2 and biogas into substitute natural gas, which can be directly injected in the natural gas grid.

The technology represents a significant advancement in the transition towards excluding fossil carbon from natural gas grids. It plays a crucial role in integrating proprietary technologies, such as anaerobic digestion and water electrolysis, into a comprehensive net-zero strategy.

The Inova Renewable gas group developed a new technology for the methanation of biogas.

Biogas is mainly composed of carbon dioxide (CO_2) and methane (CH_4). The valorization of biogas requires the removal or conversion of CO_2 to increase the CH_4 content and reach the strict requirements for injection in the natural gas grid. Inova owns technologies for the removal of CO_2 from biogas (i.e. membrane separation and amine scrubbing), but a technology for the conversion of CO_2 to increase the productivity in CH_4 was still missing. The key of the technology is the CO_2 methanation reaction, which follows the formula:

$$CO_2 + 4H_2 \longleftrightarrow CH_4 + 2H_2O$$

The reaction requires hydrogen (H_2) to proceed, which can be produced in a sustainable way by water electrolysis. The reaction is strongly exothermal, which means a significant amount of heat is produced in the reactor. Efficient heat removal is essential to prevent excessively high temperatures that could damage the reactor and its components, while also maintaining optimal low temperatures for maximum productivity. In fact, due to thermodynamic equilibrium, the reaction yield is sufficiently high only at temperature below 300 ˚C.

Inova technology utilizes a plate-type reactor to enhance the heat transfer in the reactor and to ensure that the temperature control is precise enough for the application. The plate type reactor has a large surface area, thanks to its design, as highlighted in **Figure 1**.

The large surface area of the plate-type is just one of the main features of this product. Thanks to the structure of the reactor, it is possible to cool it with boiling water, circulating with a natural draft mechanism. This is a great advantage compared to other methanation technologies, as it does not require moving parts, hence reducing the need for maintenance of such parts. Additionally, the cooling with boiling water allows an extremely precise temperature control, as the temperature of the reactor is set by the pressure in the boiling water cycle.

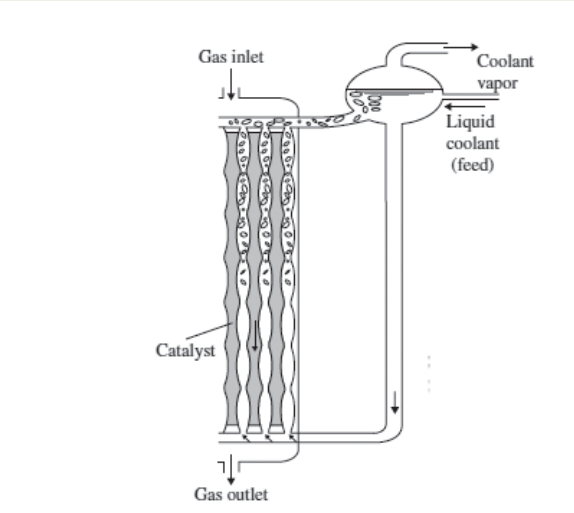

Figure 1　Schematic representation of the Inova biogas methanation reactor, highlighting the cooling system.

The core of the reactor is the biogas methanation catalyst. It was developed by Hitachi Zosen Corporation and demonstrates an excellent performance and stability in the reaction, as well as a high activity even at low temperatures. In particular, the catalyst selectively produces CH_4 from CO_2 already at 230 ˚C with a CH_4 yield above 98%.

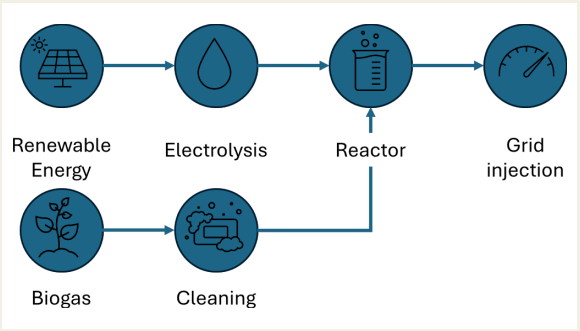

Figure 2 Block flow diagram of the power-to-gas plant installed in Gaberdorf (Austria)

■ IMPLEMENTATION

The biogas methanation reactor is installed in a pilot plant called 'renewable gasfield', an example of a power-to-gas plant in Austria.

This system consists of:

- Solar panels to produce renewable electricity.
- An electrolyser to convert water in H_2.
- A biogas plant, which provides the feed gas to the methanation reactor.
- The Inova biogas methanation reactor.

The block flow diagram of the plant is shown in **Figure 2**. In addition to these blocks, biogas is treated to remove impurities, which could otherwise damage the catalyst. Odor-carrying molecules are added to the synthetic natural gas, making it suitable for grid injection. **Table 1** shows the efficiency of the biogas cleaning system developed by Inova: both H_2S and the volatile organic compounds (VOC) are completely absent after the cleaning step.

Table 1 Efficiency of the gas cleaning section (ND = Not Detected)

	Raw biogas	Cleaned biogas
H_2S	150 – 230 ppm	ND
VOC	5 – 10 ppm	ND

Figure 3 shows the Sankey diagram of the power-to-gas plant. The first section of the plant is the water electrolyser, which shows an efficiency of about 75 %. This means that an amount of H_2 equivalent to only 75 % of the original electrical input is delivered to the methanation reactor. However, the biogas methanation reactor upgrades a low calorific gas like biogas into a high value product, which is the synthetic natural gas. The efficiency of the methanation reactor is approximately 80 %, with the remaining energy transformed into heat due to the exothermal nature of the reaction. A main advantage of the Inova methanation reactor is the production of heat in the form of high-pressure steam, which can still be utilized in other processes. Thanks to the absence of moving parts for the cooling section, the electricity need for ancillary operations is low, making the Inova solution among the most efficient options available on the market.

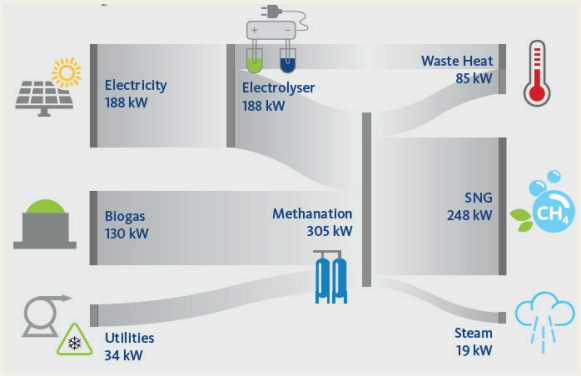

Figure 3 Sankey diagram of the power-to-gas plant.

Figures 4 shows an example of startup of the biogas methanation reactor. Here, it can be observed that the productivity of the reactor in terms of SNG grows rapidly from the startup, reaching the target values within 15 minutes from the first feed of H_2. The concentration of H_2 in the product, which is critical due to the grid regulations, drops below the maximum allowed value of 10 vol% within the first 30 minutes of operation, demonstrating the flexibility of the system. Additionally, this parameter remains stably in the allowed region over the time-on-stream, showing the reliability of the product developed.

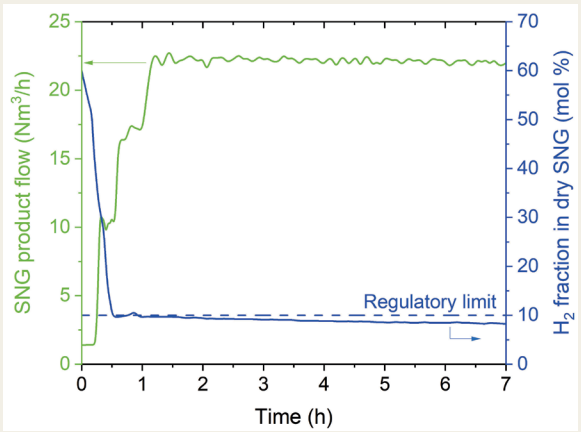

Figure 4 Example of the startup behaviour of the reactor

Figure 5 shows an example of the temperature profiles in the reactor at different reactor loads. The term reactor load refers to the percentage of gas fed relative to the nominal operating conditions. One can observe that the maximum temperature does not increase significantly with the load, showing that the reactor can be operated at different loads without exceeding the safe temperature for the catalyst. Additionally, one can observe that the fraction of the reactor occupied by the hotspot is limited and that in any case isothermal conditions are established before the middle of the reactor. This allows producing grid compliant SNG in all the conditions and operating the reactor at different setpoints, according to the availability of H_2 and biogas from the feed system.

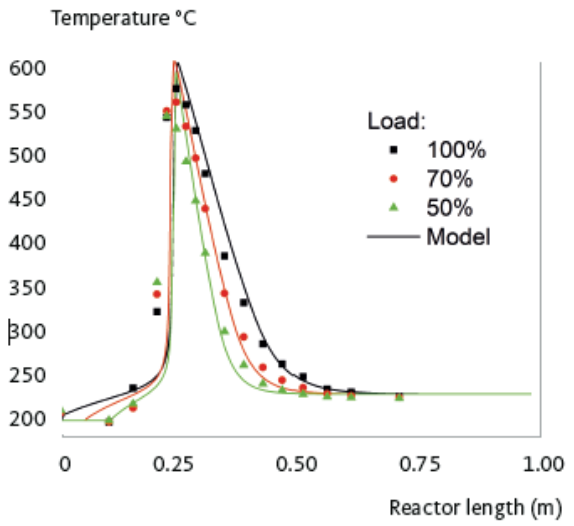

Figure 5　Temperature profiles in the reactor at different loads

■ PRODUCT FEATURES

Inova delivers full-scale solution at relevant scale, as shown in the rendering in **Figure 6**. The product can adapt to various feed gas rates, as it can be manufactured in a modular way (i.e. with one, two or three reactors). This is useful to harness volatile renewable energy inputs such as photovoltaic or wind power.

The biogas methanation reactor by Inova is an excellent solution for the conversion of biogenic CO_2. The reactor can be implemented independently from the source of biogas and adapts easily of oscillations in the quantity of biogas available and in the relative amount of CO_2 in biogas. Thanks to the short startup time, the reactor can be implemented also in regions where the H_2 availability is subject to intermittence, as the reactor load can be modified and the production of grid compliant SNG is achieved in few minutes from the plant startup.

The biogas methanation reactor by Inova is available in various scales, thanks to its modular structure. The product can be adapted to the size of the biogas plant, allowing the installation in several different configurations. The footprint required for the reactor is small. Inova provides the entire system, including the reactor, the required pre-treatment and the post-treatment unit.

The Inova biogas methanation reactor is a unique solution in the market landscape, thanks to the several advantages elucidated in the previous sections. The unique features of the product are:

1. No extensive treatment of biogas is needed.
2. High productivity in synthetic natural gas.
3. High reliability of the reactor.
4. Large scalability of the system.
5. Excellent integration of the methanation process into other systems

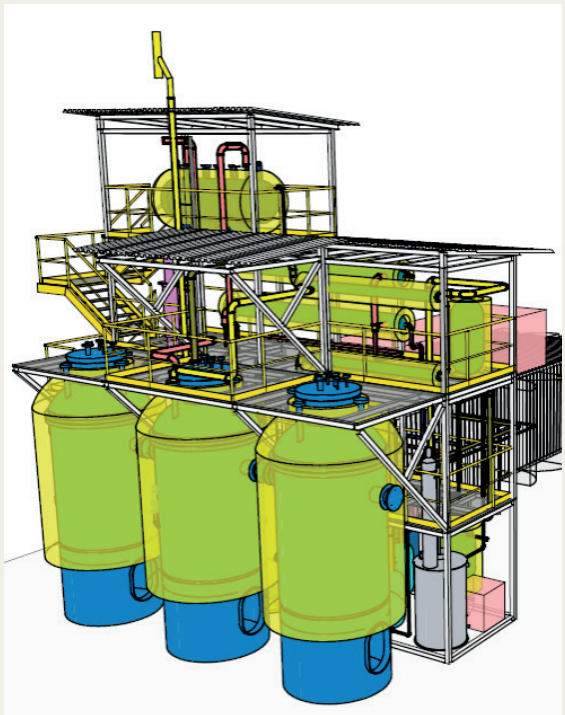

Figure 6　Rendering of the full scale methanation reactor commercialized by Inova

1. No extensive treatment of biogas is needed

The Inova biogas methanation reactor operates directly with biogas, eliminating the need for prior CO_2 separation. Processes for CO_2 removal like amine scrubbing (requiring heat) or membrane separation (requiring compression) can consume up to 10% of the biogas's energy content, which is saved by

bypassing them. This also significantly simplifies the design and operation of the pre-treatment units, which are limited to the removal of sulfur and other trace components that are present in the biogas and may harm the catalyst. The experience with the plant in Gabersdorf showed that these compounds can be removed with 100 % efficiency with a simple sorbent-based gas cleaning unit.

2. High productivity in synthetic natural gas

The Inova biogas methanation reactor achieves high CO_2 conversion in a compact unit (single stage). In the first demonstration in Gabersdorf, the product gas after one single methanation stage is compliant with grid injection specifications of Austria, which means that no posttreatment is needed (apart from water condensation and gas drying). The reactor shows 100 % selectivity to methane, which means that no side products are found in the SNG.

3. High reliability of the reactor

The reactor showed high flexibility in terms of load. In all the cases tested, ranging from 50 % to 100 % of the nominal load cases, the reactor produces grid compliant SNG. Additionally, the maximum temperature shows a limited rise with the load, remaining in the safe zone according to the specifications of the catalyst used. As the reactor does not utilize items with moving parts in the operation, the reliability of the system is extremely high and ensures extremely high availability of the system (close to 100 %). The unique design of natural draft cooling system enables the establishment of a self-adjusting regime, where the reactor autonomously adjusts its operating parameters to respond to fluctuations in the feed and corresponding heat production. This was proven with respect to variations in the flow rate or composition of the biogas.

4. Large scalability of the system

The system is composed of several reaction plates placed in parallel. This enhances the scalability of the system, as more plates can be installed, increasing the throughput of the reactor. With the scale up, the main properties of the reactor will remain unchanged, and the operation of the system will be identical. This allows a perfect integration of the system with the target biogas plants (e.g. adaptation to the throughput of the biogas plant).

5. Excellent integration of the methanation process into other systems

The reactor co-produces high-pressure steam (230 ˚C, 30 bar) from the cooling system, which is available to the customer for further use. This can be integrated in the biogas plant, for example to provide heat to the anaerobic digestion step. The reactor has a low electricity consumption, which makes it suitable for integration in any system. In particular, the reactor does not require high pressures for the operation, which simplifies the operation, especially in biogas plants. Additionally, the footprint of the reactor is small, so that the reactor can be fitted in biogas plants without large space available.

■ APPROACH AND FUTURE DEVELOPMENT

The experience with the biogas methanation reactor in Gabersdorf was essential for the Inova team to learn how to design and operate this type of plant. This allowed performing a detailed engineering of the upscaled version of the reactor, producing up to 1200 Nm^3/h of SNG.

The Inova methanation reactor will be also implemented in applications other than biogas methanation, such as CO_2 and syngas methanation. The reactor can be applied to these different fields without substantial modifications.

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