Power-to-X Plants - from ideas to industrial realisation

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Introduction

The use of renewable energy and the reduction of CO_2-emissions with the aim of carbon free industrial operation in the upcoming decades is one of the key drivers for future development in all industry branches. One of the main challenges in using renewable energy is to overcome the local imbalance of actual energy generation and energy demand. Renewable energy storage and its distribution from the place of generation to the end-user is of major importance for future success of innovative energy concepts implementing new technologies. One of the promising concepts to solve storage and distribution issues is seen in the implementation of so-called Power-to-X (PtX) plants.

Challenges for PtX plant concepts

The Power-to-X (PtX) technology uses renewable power from biomass, wind or solar energies to generate either gas (PtG) or liquid (PtL) which can be easily stored or distributed via existing pipelines. Gaseous products are typically methane (CH_4) or ammonia (NH_3), whereas liquid products are commonly methanol (CH_3OH), dimethyl ether (DME) or even synthetic fuels.

As the generation of renewable energy is typically spread over the country, it is reasonable from technical and economical point of view to consider small-scale PtX-concepts close to biogas, wind or solar power facilities compared to large-scale (mega) plants.

The most relevant carbon feedstock for Power-to-X plants is carbon dioxide (CO_2) from waste streams. "Waste"-CO_2 in combination with hydrogen will be the basis for generation of green or CO_2-neutral energy carriers.

The classical route to produce PtG or PtL is through thermochemical synthesis via heterogeneous catalysis, but biological pathways are under current development as well. Although the process principles are basically known and lab scale results are available, without proven data of long-term reliability and operability for such process units and plant concepts the market acceptance is expected to be difficult.

Pilot and/or demonstration plants can assist to provide the required long-term operational data. The design of such demonstration plants has to consider not only the desired name plate capacity but also the process configuration under transition modes or feed stock fluctuations and its consequences in terms of process stability and operational flexibility.

Only with a customized plant concept and detailed discussion between technology provider and qualified pilot plant manufacturer, an optimized pilot plant concept can be elaborated.

Power-to-Gas (PtG) – Formation of Methane (CH_4)

PtG is the first choice of technology when it is the purpose to produce a synthetic natural gas (SNG), which then can be injected into existing natural gas grids. The production of CH_4 from CO_2 and H_2 can be expressed by the following formula (Sabatier process):

$$\mathbf{CO_2 + 4H_2 \rightleftharpoons CH_4 + 2H_2O}$$
$$\Delta \boldsymbol{H} = \mathbf{-165,0\ KJ\ mol^{-1}}$$

The methanation reaction is strongly exothermic, where high pressures and low temperatures are beneficial to shift the reaction towards the direction of CH_4 formation. The catalysts typically applied are based on Nickel catalysts or noble catalysts like ruthenium. The highly exothermic reaction challenges the reactor design in terms of intermediate cooling demand to avoid high temperature in the catalyst bed causing severe catalyst degradation or even damage. CALORIC is familiar with the design and installation of such methanation units (Fig. 1).

Fig. 1: Methanation unit ©CALORIC

Recent developments have shown that the conversion of CO_2 and H_2 to CH_4 can also be achieved on a biological path by using special bacteria (Archaea). An advantage of biological methanation are the mild exothermic conditions, however the process conditions especially during transitions modes have to be maintained at any time in a way that these bacteria stay "healthy" and will not reduce significantly its efficiency in producing methane.
The operation of demonstration plants has shown that such units are able to produce methane in a quality allowing injection into the local gas grid. Fig. 2 shows a biological methanation plant built by CALORIC.

Fig. 2: Biological methanation plant ©RES

Power-to-Liquid (PtL) – Formation of Methanol (CH_3OH)

PtL is the choice when energy carriers with a high energy density are required, which can be transported by trucks or shipped easily to the end-user. One potential PtL-product is methanol, which has the benefit due to its universal applicability as a fuel for the transport sector, feedstock for fuel cells or as a base chemical. Today, methanol is mainly produced in large scale plants (mega methanol plants) on the basis of carbon monoxide (CO) rich syngas coming from natural gas reforming or coal gasification. To produce methanol based on CO_2 as a feedstock is quite a new application. Methanol formation from CO_2 can be expressed by the following main exothermic reaction:

$$\mathbf{CO_2 + 3H_2 \rightleftharpoons CH_3OH + H_2O}$$
$$\Delta \boldsymbol{H} = \mathbf{-49,4\ KJ\ mol^{-1}}$$

High pressures and low temperatures are beneficial to generate methanol. The process is typically operated between 50 to 100 bar and temperatures 200 and 300 °C. To achieve a high yield of methanol, unreacted syngas must be recycled. Compared to the reaction to generate CH_4 from CO_2 and H_2, the reaction is over three times less exothermic and therefore less challenging to handle. As a consequence standardized equipment for adiabatic reactors can be used then. For the thermochemical synthesis, commercial catalysts based on copper are available on the market.

Within the process a certain amount of undesired byproducts (e.g. higher alcohols) are generated. To upgrade the raw methanol to fuel grade or chemical grade, purification by distillation is needed. The energy demand for the downstream processing depends on the requirement of the product purity as well as the heat integration concept applied.

Due to the conventional process conditions that requires downstream purification step(s) in order to get liquids in industrial quality (purity) the PtL-plants are facing relatively high investment costs, which can be considered as the main disadvantage of this technology.

Conclusion

The application of PtX technologies plays a major role for the success of renewable energy concepts in the near future. Several technologies are ready to be tested in pilot and demonstration plants for its feasibility. In general, for small scale applications the economics for PtG- and PtL-plants are mainly driven by investment costs whereas for large scale applications feedstock prices will become more dominant.
For a breakthrough of these technologies, especially for distributed, small scale applications, it is important to find process concepts which reduces significantly undesired by-products during the synthesis and to apply heat integration concepts to decrease the costs or even the number of required purification step(s). Further details on techno-economical subjects can be found in Dieterich et al. (2020).

With the long-term experience in the hydrogen and syngas business, CALORIC is able to provide customized solutions. Focusing on customer's needs, CALORIC's pre-assembled and automated plants fulfil the demands of the most challenging requests – from ideas to industrial realisation.

References

Dieterich et al. (2020): Power-to-liquid via synthesis of methanol, DME or Fischer–Tropsch-fuels: a review. Energy & Environmental Science.

Electrochaea (2020). Stromspeicherung und Dekarbonisierung: Electrochaeas Power-to-Methane-Technologie überzeugt mit hervorragenden Projektergebnissen. Presseveröffentlichung 19.03.2020. Link: http://www.electrochaea.com/wp-content/uploads/2020/03/PM_Electrochaeas-Power-to-Methane-Technologie-%C3%BCberzeugt-mir-hervorragenden-Projektergebnissen_final.pdf

Caloric (2017): CALORIC builds pilot & demonstration plant for Electrochaea's innovative biomethanation process. Link: https://www.caloric.com/en/project/caloric-builds-pilot-demonstration-plant-for-electrochaeas-innovative-biomethanation-process/