Power-to-Gas –
A solution for energy storage

by Doris Hafenbradl and Mich Hein

Power-to-Gas technology provides a solution for the energy storage challenge created by the increasing deployment of renewable energy. The process relies on the ability to convert electrical energy from renewable sources into chemical energy that can be stored and retrieved at will. In a first step of the process, H₂ is generated via electrolysis of water. A catalytic process then produces pipeline grade CH₄ using the H₂ and CO₂, which can be provided from various sources, such as biogas, landfill gas or fermentation off gases. Electrochaea uses a thermophilic methanogenic Archaea as a biological catalyst to generate methane. This Archaea has proven to be robust at large scale and demonstrates a high production rate of CH₄. Electrochaea is currently working on a commercial demonstration project in Denmark (www.BioCat-project.com) in which methane produced with our biocatalyst will be injected into the local natural gas grid.

1. INTRODUCTION

The increasing deployment of renewable energy is creating challenges for managing the electricity system. In today’s grid, electricity demand and supply need to be balanced at all times. With a growing share of wind and solar energy, which generate electricity intermittently and generally independent of demand, the electricity grid will experience more frequent and prolonged periods of supply/demand imbalances (Figure 1). Such imbalances will lead to more volatile power prices and, in severe cases where grid capacity is constrained, to the curtailment of wind and solar energy production and a net loss of the available renewable energy.

Energy storage via Power-to-Gas technologies is being proposed as a powerful solution to address these problems.

2. TECHNOLOGY DESCRIPTION

In power-to-gas (P2G) energy storage, electrical energy is converted to chemical energy in the form of methane (see Figure 2). If wind, solar, or other sources of renewable energy are used, a low-carbon gas can be produced that is fully compatible with the currently existing gas delivery and utilization infrastructure.

The first step in the P2G production chain consists of the production of hydrogen and oxygen through electrolytic water splitting. Most of the electric energy required for electrolysis (70-80%) is conserved in the hydrogen (H₂) molecule and some of the energy is released as heat. In the second step, hydrogen is combined with carbon dioxide (CO₂) and catalytically reacted to methane (CH₄), the principal component of natural gas. If the composition of the product gas meets the gas quality requirements of the natural gas network, it can be injected into a natural gas pipeline at the point of production (analogous to biomethane).

The chemical reactions for the electrolysis and the methanation steps are:

Electrolysis:  4H₂O -> 4H₂ + 2O₂ + Heat
Methanation:  CO₂ + 4H₂ -> CH₄ + 2H₂O + Heat
Net Reaction:  CO₂ + 2 H₂O - > CH₄ + 2O₂ + Heat

The required inputs for the system are therefore simple and straightforward.

Inputs
■ Water
■ Low-cost or stranded electricity or H₂
■ CO₂ from biogas, fermentation, or other sources
■ Biological catalyst

Outputs
■ Pipeline-grade methane for direct grid injection
■ Oxygen for industrial or medical applications
■ Heat for on-site use or district heating grids

Once in the network, the gas can be stored for days, weeks, or even months. The large storage capacity of the gas grid combines with low leakage rates to enable sea-
Personal storage, a functionality of particular importance in regions with large seasonal swings in renewable energy production.

The P2G product gas can also be transported geographically through existing pipelines to demand centres further away. This is useful in regions with power grid bottlenecks or location mismatches between power demand and renewable energy resources.

3. UTILIZATION PATHWAYS

The chemical identity between P2G product gas and natural gas means that electric energy from intermittent renewables can be made available for a broad range of energy sectors.

The most obvious utilization pathway is to use the gas for power production in combined-cycle gas turbines.
Such CCGT plants are anticipated to be required in future energy systems to balance the power grid, and P2G can deliver a low carbon fuel to these turbines.

Another important utilization pathway is the heat sector, which in many countries is difficult to decarbonize due to the limited amount of biomass (for biomethane production) that can be sourced sustainably. P2G offers an opportunity to increase the share of low carbon gas in the gas grid without additional biomass.

Lastly, product gas from P2G can also be used in compressed natural gas (CNG) vehicles to decarbonize the transportation sector. The German carmaker AUDI AG was the first to launch a vehicle (A3 g-tron) that can be purchased with e-gas, Audi’s renewable gas product generated entirely from wind energy. Renewable gas will also be a fuel of choice to decarbonize parts of the transportation industry that cannot be electrified, such as long-distance heavy-duty vehicles.

4. THE ELECTROCHAEA PROCESS

Electrochaea [3] is using a selectively evolved, not genetically modified, strain of *methanogenic archaea* for the methanation reaction. Archaea have populated Earth for more than three billion years and are believed to have been among the first living organisms on the planet. Along with bacteria and eukaryotes, they are the third kingdom of life in the phylogenetic taxonomy. Archaea have been identified only about 30 years ago [4] and populate mostly extreme environments like hot springs, black smokers and salt lakes.

The Electrochaea strain of archaea is a single-celled, autotrophic organism feeding exclusively on hydrogen and carbon dioxide, while producing almost exclusively methane. The strain exhibits many characteristics that make it particularly suitable for industrial environments:

- Extremely fast reaction rates;
- Very high tolerance to contaminants (H₂S, O₂, particulates, etc.);
- High substrate and product gas selectivity;
- Mild operating temperatures (60-65°C);
- High longevity (self-reproducing, self-maintaining);
- Fast ramping rates (quick response to fluctuations in H₂ supply);
- Very high carbon conversion efficiency (98.6% of carbon is converted to CH₄).

The high tolerance of the microbes towards a range of gases and chemicals, which may be components of biogas or other waste gas streams, allows the process to use a various sources of carbon dioxide. The reduction of the CO₂ footprint can also be one of the commercial drivers for implementation of a power-to-gas plant.

Electrochaea believes that the technical characteristics of its microbes will translate to lower capital and operating costs as well as higher operating flexibility compared with the chemically driven Sabatier process.

The biomethanation process has been demonstrated to be robust and scaleable to large scale for energy storage. Current battery based solutions will not provide a
solution long term considering that the required storage capacity is expected to be in the 20-40 TWhel range (see Figure 3).

5. THE BIOCAT PROJECT

The BioCat Project marks the latest step in Electrochaea’s scale-up and de-risking pathway. Building on a pre-commercial demonstration project executed in 2013 in Denmark, and supported by EUDP, EON, EWZ, Energie360° and NEAS Energy, BioCat is anticipated to lift the company’s technology to market readiness. The Project is partially funded by ForskEL, a technology development support program administered by the Danish transmission grid operator Energinet.dk.

The BioCat Project is located at the wastewater treatment plant Avedøre south of Copenhagen, Denmark, which is operated by BIOFOS. The plant will use hydrogen produced from a 1-MW alkaline electrolyzer manufactured by Hydrogenics Europe. The carbon dioxide is delivered from untreated biogas produced through the anaerobic digestion of sewage sludge by the wastewater plant. The product gas is injected into a 4-bar distribution grid managed by HMN Naturgas, while the by-products heat and oxygen are recycled in the on-site wastewater operations. The electrolyzer is anticipated to deliver balancing services to the Danish power grid and will be operated according to an optimized trading strategy developed by NEAS Energy. AUDI AG provides engineering and operating advice, while Insero Business Services provides project management and communications support.

Once operational, the BioCat facility will be one of the world’s largest P2G plant operating with biological methanation.

To find out more about the BioCat Project, visit the project’s website at: www.biocat-project.com

REFERENCES

[2] adapted from ZSW, Erneuerbares Methan aus Okstrom, April 2012
[3] Electrochaea is a start-up company located in Planegg, Germany. The company is developing a disruptive grid-scale energy storage technology. Based on the execution of an ambitious scale-up and de-resiking process market readiness is expected in 2016. www.electrochaea.com

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