

ForskEL Project #12603: “P2G-BioCat – Phase 1”

Final Report: June 30, 2014

The purpose of this document is to provide Energinet.dk with a final statement about the activities and results in the ForskEL project #12603, “Power-to-Gas via Biological Catalysis – Phase 1”. This final report accompanies a request for reimbursement of expenses incurred by Electrochaea.dk ApS (“ECDK”) since the last interim report in the execution of the Project.

Highlights of Activities & Results

- The wastewater treatment plant Avedøre has been selected as the site for the execution of ForskEL project #12,164, “Power-to-Gas via Biological Catalysis – Phase 2” (“BioCat 2”).
- Desktop studies and lab-based prototyping work have produced valuable insights for the development of an optimized bioreactor to be used in BioCat 2.
- An electrolyzer configuration was identified and developed in collaboration with Hydrogenics Europe N.V. suitable for a MW-scale demonstration in BioCat 2.
- Total project expenses amount to DKK 2,364,491 and are well below the budget ceiling.

Activity Review

Site Selection

From the start of the Project in February 2013, ECDK’s senior managers have undertaken considerable efforts to identify candidate sites for the MW-scale demonstration project (“BioCat 2”). Conversations were held with several biogas-producing industrial facilities throughout Denmark, including agricultural biogas plants and wastewater treatment facilities in Aarhus, Fredericia, and the greater Copenhagen area.

Key criteria for the selection of the plant included:

- Availability of sufficient carbon dioxide in the form of raw biogas or as a pure stream
- Existing gas grid connection or proximity to a gas distribution grid

- Availability of other critical resources such as land, electrical power, and water
- Existence of environmental and safety permits to operate a power-to-gas facility
- Enthusiasm and support of site operators for the project
- Possibility of utilizing existing control system, operators, laboratory, and shared facilities

The wastewater treatment plant Avedøre in the municipality of Hvidovre (south of Copenhagen) was selected because it satisfied all the critical issues for a successful delivery of BioCat 2.

Reactor Development

ECDK used a combination of desktop studies and laboratory tests to collect data for the development of an optimized bioreactor. At the beginning of the Project, the BHR Group (an external engineering consultancy based in the UK) was commissioned to perform a preliminary analysis of data collected in previous experimental work at ECDK and at the University of Chicago. The investigation focused on *in silico* predictions and analysis of design parameters. From this work, it was concluded that key engineering considerations for the final reactor design will be i) mass transfer of hydrogen to the archaea, ii) energy requirements for mixing to assure high mass transfer rates, and iii) management of pressure drop at high operational efficiency to maintain catalyst viability.

The work by BHR was complemented by laboratory tests using two different types of reactors to evaluate the performance of the biological catalyst under different pressure and flow conditions. Using these reactors and design and performance parameters defined by the external consultants IMPACT Technologies and BHR, ECDK has measured several important performance parameters of the archaea under different operating conditions. For instance, viability of the cells was demonstrated through pressure ramping and isobaric operations ranging from 1 to 10 barg, and cell survival and catalytic conversion was demonstrated at up to 13 barg. CO₂ conversion efficiencies have ranged between 60% and 99%. Resilience was demonstrated for pressure ramping rates consistent with commercial reactor operation, through a series of controlled pressurization and de-pressurization cycles. High rates of pressure reduction were shown, as anticipated, to reduce cell viability, informing reactor design criteria for managing depressurization.

Furthermore, data was collected with regards to ramp-up time from quiescent to rapid cell division to full catalytic mode; time limitation on ramping from ambient temperature to operating temperature; volumetric conversion efficiencies at volumetric turnover rates of between 10 and

300 VVD; impact of diluent gas concentrations on conversion efficiency; and volumetric productivity in steady-state operations.

Further tests were conducted with a reactor designed and built by Electrochaea and employing a static mixing system. Using comparable conditions as applied in the experiments with the pressurized CSTR, these tests provided information to inform design considerations to impact mass transfer and cell viability in a new reactor geometry.

These reactor development studies under the Project provided important data to guide the design of an optimized bioreactor to be used in BioCat 2.

Electrolyzer Specification

ECDK has collaborated with Hydrogenics Europe N.V., a leading manufacturer of electrolyzers, to better understand the technical and economic aspects of closely integrating a methanation system with an electrolyzer. The specifications of an alkaline electrolyzer to be used in BioCat 2 were defined. This hydrogen production system will be an advancement of the current Hydrogenics S1000 electrolyzer model and feature two hydrogen production units with three cell stacks each, delivered in two 40-ft containers.

Communications & Information Dissemination

The work undertaken in the Project was communicated to Electrochaea's stakeholders and the greater public at several occasions over the course of the Project. Conference appearances in which the Project was featured included:

- UK Biomethane Conference (Birmingham, UK; 21.05.2013)
- St. Gallen Forum for Renewable Energy (St. Gallen, CH; 24.05.2013)
- European Biomass Conference (Copenhagen; DK; 03.06.2013)
- Conference of Swiss Industry Association for Water and Gas (Pfäffikon, CH; 14.06.2013)
- 2nd Power-to-Gas Forum by OTTI (Regensburg, DE; 10.09.2013)
- CO₂ Utilization Conference (Brussels, BE; 31.10.2013)
- 3rd Power-to-Gas Forum, Energy Storage Conference (Düsseldorf, DE; 27.03.2014)

Project Spending & PSO Funding

Total project expenses amount to DKK 2,364,491, of which DKK 1,234,648 has already been requested for reimbursement. This final report is accompanied by another reimbursement request for DKK 183,829, which brings the total PSO funding to DKK 1,418,477 or 59.99% of the total cost. Overall, 48% of the total budget has been utilized and no expense category has exceeded its budget.

The audit report by KPMG is available as a separate document.