Final report

1.1 Project details

Project title	Power-to-Gas via Biological Catalysis (P2G-Biocat)
Project identification (program abbrev. and file)	2014 -1-12164
Name of the programme which has funded the project	ForskEL
Project managing company/institution (name and address)	Electrochaea.dk ApS Chr M Østergaardsvej 4A DK 8700 Horsens
Project partners	Hydrogenics Europe NV Nijverheidsstraat 48c BE-2260 Oevel Belgium NEAS Energy A/S Skelagervej 1 DK-9000 Aalborg Denmark HMN Gashandel A/S Vognmagerevej DK8800 Viborg Denmark Insero A/S CHr M Østergaardsvdj 4A DK-8700 Horsens Denmark BIOFOS A/S Refshalevej 250 DK-2432 Copenhaven K Denmark Audi AG Eitlinger Strasse Tor 10 85045 Ingolstadt Germany
CVR (central business register)	3387 3956
Date for submission	5 April 2017

1.2 Short description of project objective and results

The overall objective of the P2G-BioCat project was to design, engineer, construct, and operate a 1-MW power-to-gas facility to produce and inject grid-quality methane under intermittent operations using hydrogen from alkaline electrolysis and a methanation reactor based on biological catalysis, and to provide profitability analyses under current and future expected market conditions, identify regulatory inhibitors and barriers, optimal operating strategies, and current and future market potential for Power to Gas in Denmark. The project's technical and business goals have largely been achieved and, as described in greater detail in the final report, are encouraging for commercial development of biological methanation and Power-to-Gas for the benefit of the Danish energy system.

Formålet med P2G-BioCat projektet var at designe, igangsætte, konstruere og operere en 1-MW Power-to-Gas facilitet, som producerer og injicerer metan af gasnet-kvalitet under periodiske operationer ved hjælp af brint og en biologisk katalyse baseret metanisering reaktor, at udvikle rentabilitetsanalyser rettet mod nuværende og fremtidige markedsforhold, og at identificere reguleringsbegrænsninger og barrierer, optimale operationsstrategier, og nuværende og fremtidige markedspotentialer for Power-to-Gas i Danmark. Projektet tekniske og erhvervsmæssige mål er overordnet set nået, og som beskrevet i den afsluttende rapport, er resultaterne opmuntrende for en kommercielle udvikling af biologisk metanisering og Power-to-Gas, som vil komme det danske energisystem til gode.

1.3 Executive summary

Power-to-gas ("P2G") is an innovative and disruptive energy storage solution ideally suited for the Danish energy system. Its key advantage is the unique combination of value propositions that combine to solve multiple challenges posed by Denmark's accelerating transition to a low-carbon economy. Electrochaea along with its partners Hydrogenics, Audi, Energinet.dk (acting in its capacity as the TSO), NEAS Energy, HMN Gashandel, and Insero have executed on the implementation of a novel and scalable biological P2G system under BioCat P2G to address these challenges. The project is the largest biological P2G system in the world and has substantially de-risked the technology, regulatory path and business models.

The BioCat P2G project demonstrates a new and powerful option for Energinet.dk by pioneering the large scale deployment of a proprietary and flexible P2G system to capture value from the growing supply of intermittent and renewable power to the Danish energy system. The characteristics of P2G with biological methanation effectively allows full integration of intermittent renewable power into the heat and gas grids to capture, store and deploy renewable energy resources for optimum benefit. Each of these grids distributes between 35 and 50TWh of energy to customers each year.

The system-wide benefits of P2G are without precedent in the field of energy storage and system integration. By storing low-cost or stranded electricity as methane in the existing natural gas infrastructure, P2G offers practically unlimited storage capacity and "charging" durations in the nearly 45TWh of energy storage capacity in Denmark's gas grid, the largest energy storage reservoir available to Denmark. Other unique features include the ability to provide power grid balancing services, the dissociation of charging and discharging in terms of timing and power rating, the ability for geographic energy transmission via pipelines, high scalability (100 kW to >50 MW), and the ability to connect P2G units to both the transmission and distribution grids. A robust deployment of P2G in Denmark could help integrate the nation's modern and well-distributed electricity, gas, and heat grids.

The BioCat P2G system installed at the BIOFOS Avedøre wastewater treatment center is a commercial-scale 1MW capacity power-to-gas facility connected to both power and gas grids. The system operated for 8 months during the project, including commissioning. During the project, the system used 42,193 Nm^3 biogas, 170 m^3 water and 708,215 kWh electricity for system operations and to produce 129,290 Nm^3 hydrogen for methanation of ~16,000 Nm^3 CO_2 from the the biogas and making available 85,000kWh heat for use at Avedøre's facility. The system operated at variable loads and was used intermittently through 3 seasons until December 22, 2016.

The key innovations in this project: use of a biological catalyst in a pressurized commercial scale reactor, intermittent use of the system to respond to available power, resiliency of the biocatalyst to raw biogas, contaminants and a challenging duty cycle were all well demonstrated. The biocatalyst performed well under these conditions, with raw biogas as the carbon dioxide source. The system required a single biocatalyst inoculation at the start of the project, with no supplemental addition or replacement. The reactor and biological catalyst in BioCat are capable of producing grid quality gas - greater than 97% methane, <2% Hydrogen, <1% CO_2, and <5ppm H_2S in the product gas at pressures between 5 and 9 barg. The only additional required step for grid injection is drying to remove water vapor.

The BioCat system has been used effectively for dissemination of both technical and economic information regarding the use of P2G for energy storage and system integration through site visits, citation by third parties and via the Project website which provides updates on progress and events in and a primer for understanding biological methanation and P2G technologies in general. All major project goals and objectives were achieved, including the key technical and economic parameters for construction of a P2G business case in Denmark.

From P2G-BioCat we conclude that the integrated technologies function well in the planned context (anaerobic digestion, electrolysis, biogas production, biological methanation and heat recovery) and can scale to much larger sizes to meet the needs of the Danish power and gas systems. Power-to-Gas can be deployed to store renewable power in the form of renewable natural gas, depressing fossil fuel use, decarbonizing the natural gas grid, and making good use of renewable electricity produced in excess of immediate demand. Heat generated in the P2G process is integrated into the local environment for biogas production or wastewater treatment. System operations, personnel and technology requirements are well suited to deployment at wastewater or anaerobic digestion facilities. Capital and operating costs for the project, coupled with analysis of two years of market pricing for products and energy inputs support an interactive techno-economic model for the Danish Market.

In Denmark the biggest barriers to commercialization are currently 1) high cost of renewable power due to tariffs, taxes and fees that mask the low market price of power when production exceeds demand, and 2) current lack of clarity on the pricing, product designation and future regulatory environment for a "new" gas product produced by methanation using renewable energy. The P2G-BioCat project pioneered the investigation of these issues and the Consortium has engaged effectively with Energinet.dk, and regulatory authorities to illuminate these market and economic issues and suggest solutions that will enable rapid commercialization.

BioCat is scheduled to continue operations at Avedøre to incrementally improve the technical and economic performance of the system, perform key experiments on industrial control of biomethanation with academic partners, develop cost down strategies for both capex and opex and provide a demonstration site for Energinet, academic institutions and future customers and partners for commercial deployment in Denmark and other markets. Electrochaea and BIOFOS are committed to continued operation of the BioCat site to showcase this exciting addition to Denmark's renewable energy portfolio and to accelerate commercial deployment.

1.4 Project objectives

The overall objective of the P2G-BioCat project was to design, engineer, construct, and operate a 1-MW power-to-gas facility to produce and inject grid-quality methane under intermittent operations using hydrogen from alkaline electrolysis and a methanation reactor based on biological catalysis.[1]

In addition to these technical parameters, the project sought to develop sufficient insights into the economic and commercial aspects of P2G energy storage in Denmark to develop a scalable business in this market. Among these assessments were profitability analyses under current and future expected market conditions, identification of regulatory inhibitors and barriers, optimal operating strategies, as well as current and future market potential considering the electricity market and carbon dioxide supply. The project included the goal of demonstrating the system's ability to provide frequency regulation in the Danish electricity grid, and estimate the value provided therein.

The project had inherent risk due to complexity of integrating several technologies in a 'first of its kind' demonstration, participation of 6 partners requiring integration of physical assets, signal exchange and controls coordination. In addition, the project required the definition and registration of a new product to be injected into the Danish gas grid, and relied on success of a second project, ENZUP, for supply of carbon dioxide to the P2G BioCat reactor.

1.4.1 Project Evolution

The project evolution was impacted by a set of delays – most of which occurred at its start and were related to contract negotiations, late accession of one of the Partners to the Consortium agreement and time required for securing the final capital for the project. These issues resulted in approximately 6 months of delay, after which the project schedule was

[1] Definitions for this project:

- *1 MW denotes the nominal power rating (input) of the electrolyzer,*
- *1 MW denotes the nominal power rating (input) of the electrolyzer,*
- *power-to-gas facility includes the main components (electrolyzer + bioreactor) as well as the process controls, facility tie-ins, and other balance of plant equipment,*
- *inject means to dispose product gas in a gas pipeline operated by HMN Gashandel and connected to a 5-bar distribution grid whose M/R station is located approximately 1.5 km north of our site,*
- *grid-quality methane means a product gas in compliance with local gas grid regulations,*
- *intermittent operations means single- and multi-hour operating patterns in which the facility is run at either constant or varying power input followed by down time,*
- *alkaline electrolysis means a hydrogen production technology specifically designed for power-to-gas applications by Hydrogenics (the S2500 electrolyzer),*
- *methanation reactor means a new bioreactor specifically designed for this project by Electrochaea and operating with a mono-culture of methanogenic archaea.*

reset. One additional delay of approximately 6 weeks was incurred during negotiations with potential EPC contractors for delivery of the BioCat reactor and balance of plant. This delay overlapped with a similar delay in the projected timeline for construction and delivery of the electrolyzers. Once the EPC contract was signed with Zeton, civil works on the site, construction and delivery of the BioCat reactor and electrolyzers to the site were on time and without major incident. The reactor and balance of plant arrived in week 50 of 2015, as agreed and the electrolyzers arrived on site at Avedøre in week 3 and week 8 of 2016. System assembly and site acceptance testing for individual components was completed by the end of March, 2016, as planned, and the reactor and catalyst were commissioned in the second week of April, 2016.

As for all first of a kind projects, a number of challenges to the project execution resulted in an accumulation of delays of an additional 3 months during execution. An extension was granted to the project through December 31, 2016 to accommodate these delays. These operational delays did not alter any major goals of the project, but did result in additional costs that were borne by Project Partners. For transparency and shared learning we provide details of the project evolution, challenges and solutions. We regard the majority of these project challenges as within the scope of expectations for projects of this sort and report that the Partners all contributed to timely and constructive solutions.

Five factors had material impacts on the evolution, quality and speed of work on the BioCat project once commissioning had begun:

- the biggest impact on the project scope and execution was the failure of the adjacent ENZUP project on the Avedøre site, that eliminated the source of CO2 feedstock for the BioCat reactor, changed the operational envelope and testing strategy for the BioCat system, and resulted in redesign, altered equipment needs and interconnections for grid injection.

- the failure of ENZUP to delivery CO2 also shifted the gas supply to biogas delivered from BIOFOS. Due to prior contractual commitments and operational cycles at Avedøre beyond Electrochaea's control, biogas was not always available for system operation (and had not been promised for continuous availability) and its quality varied significantly depending on treatment strategies for the biogas at the site.

- in the first four months of operations, signal integration and minor defects in temperature controls or valves resulted in unanticipated shut down of one or both electrolyzers. This resulted in immediate system shut downs on a daily basis, and required constant attention to the electrolyzers. These issues have been largely resolved.

- operational challenges with the BioCat system flare resulted in frequent shutdowns due to flare failure or flare control failure; the flare manufacturer was non responsive during the entirety of the project and the flare problem was only resolved 3 months after the official end of the BioCat project.

- Integration and control of the heat exchange interconnect between the site and BioCat was not well designed or executed (by a third party engineering firm), and as a result the frequent absence of cooling capacity required unplanned shut down or delay of BioCat operations or system testing on numerous occasions. This issue persists despite Partner and site efforts at resolution and will be addressed in the BioCat continuation.

While these factors adversely impacted the planned and controlled operation of the system, the cumulative effect was to demonstrate that the core of the BioCat system – biocatalyst and reactor – were capable of rapid and unanticipated shutdowns and subsequent restart, without loss of function or catalytic capacity.

The Project Supervisor and Partner teams focused on solutions to these problems and as a result, all of the major performance metrics for the P2G Biocat plant have been met. Of the discrete goals not reached, two are related to the major risks identified above, and are described below in the assessment of project risks.

1.4.2 Project Goals and Objectives

The key objective not met during BioCat was the actual injection of gas onto the Danish grid. Essentially everything had to go as planned to meet this goal. This objective required the substantial completion of all of the technical goals, physical connection of BioCat to the gas injection station, completion of a 2km gas line and injection station improvement (by HMN), appropriate performance of all of the systems, availability of CO2 supply for methanation, and the definition and regulatory acceptance of a new gas product. We have achieved all of these goals either during or since the completion of P2G BioCat, but due to the absence of CO2 as feed gas, we require the installation of a condenser system for the gas product to reach an acceptable water content for injection. This condenser will be added to the system in the next phase of BioCat.

Table 1.1 summarizes the project Goals and Major Objectives as provided in the project proposal. Included after each goal is a very short assessment of the progress against each goal. As is evident in this table, the P2G BioCat project achieved all its major goals, with a small number of goals remaining to be reached on further operation of the system.

The main objectives of the P2G BioCat project are presented in Table 1.1 below:

Table 1.1: Goals and expected findings from P2G-BioCat Project

Overall Objective	Specific Results and Insights Produced from the Project

Knowledge to design, engineer, construct, operate, and maintain a P2G facility at MW-scale	• Demonstrate ability to inject pipeline-grade methane **(yes)**
	  ○ Delivery of pipeline-grade methane from bioreactor **(not completed)**
	• Data about electrolyzer and bioreactor performance
	  ○ Energy and mass conversion efficiency at various capacity factors **(yes)**
	  ○ System responsiveness to changes in electricity supply (electrolyzer) hydrogen flow (bioreactor) **(yes/yes)**
	  ○ Volumetric productivity of system in optimized/pressurized bioreactor **(yes)**
	  ○ Real-time measurement of product gas composition **(yes HMN and EC concurrence of measurements)**
	• Insights into operability, reliability, and maintainability **(yes)**
	  ○ Plant availability factor over multi-month operating period **(yes, partial)**
	  ○ Variability of CO_2/biogas quality (**yes, for biogas; no CO2 available on site)**
	  ○ Reliability of bioreactor, electrolyzer, and other process equipment **(yes, for 8 months)**

	○ Performance of analytical instruments under varying conditions **(yes)** • Insights into durability of the biocatalyst **(yes)** ○ Reproduction rates and cell culture dynamics under different operating conditions **(yes)** • Demonstration of by-product recycling capabilities **(partial)** ○ Recovery and reuse of heat and oxygen in biogas production and wastewater treatment **(heat recycled from reactor but not electrolyzers; eliminated oxygen use goal due to capital cost of piping on site)** • Engineering knowledge on the scale-up, operability, and maintainability **(yes)** ○ Data for further scale-up and reactor optimization analysis **(yes)** ○ Minimization of nutrient inputs for biocatalyst maintenance **(yes)** ○ Degradation rates of key process equipment **(yes, none observed)** • Understanding of construction and permitting requirements **(yes)** ○ Synergies with existing permits at wastewater plants **(some, for waste disposal)** ○ Requirements for new permits required in Denmark (**yes – significant learnings and new standards established)** • Schedule requirements from concept to start-up **(yes)** • Process control knowledge from the integration of the CO_2 and hydrogen supply with methane production and natural gas grid injection **(yes for biogas and hydrogen supply; no CO2 available on site)** • Capital cost, operating, and maintenance expense definition **(yes)**
Demonstrate ability to dynamically follow loads and provide primary and tertiary regulation services	• Application to have electrolyzer approved for grid balancing services **(yes)** ○ Understanding of approval requirements **(yes, new findings)** • Demonstration of the technical ability to provide ancillary services **(partial)** ○ Measurements of the rate at which the process can use/release power to/from the power grid to regulate the grid's frequency **(yes, tested reactor and biocatalyst response)** ○ Measurement of the impact on fluctuating hydrogen flow on biocatalyst conversion efficiency, longevity, and response rate **(yes)**
Optimization of trading strategy	• Development of a value-maximizing trading strategy under current and expected future market conditions **(yes)** • Development of a communication link between the P2G facility and an energy trader **(yes)**
Refinement of unit economics	• Identification and quantification of value sources in Danish market **(yes)** • Refinement of unit capital costs and O&M expense factors **(yes)** ○ Understanding of scaling factors related to capital costs **(partial)** ○ Understanding of degradation factors and depreciation expense (**insufficient time, other than for electrolyzer)** • Determination of financial value of: ○ Methane, in consideration of any applicable subsidies **(yes, new product definition)** ○ Oxygen and heat, in consideration of the value generated to a wastewater treatment facility **(yes)** ○ Ancillary services, based on real-world market conditions **(partial)** • Identification of actual power costs in consideration of the fee and tax exemptions applicable to P2G **(yes)** • Refinement of biocatalyst nutrient costs **(yes)** • Calculation of return on investment under current and expected future market conditions **(yes, under several scenarios)**
Understanding of market structure, dynamics, and potential	• Identification of market trends and regulatory aspects that prohibit, inhibit, or support P2G in Denmark **(yes)** • Quantification of the technical potential of P2G in Denmark **(yes)**

1.4.3 Managing Project Risks

Several risk factors contributed to delays in reaching the basic objectives, goals and associated milestones for P2G Biocat. Most of these risks were identified in the Project Proposal and in most cases contingency planning and general awareness prevented loss of major objectives or specific project goals. All critical functions of the system impacted by these risks have been addressed. The dominant risk issues identified in the project proposal are listed below, including descriptions and identifiable causes and mitigations of those factors that adversely impacted the project:

Financial Risks:

- Initial proposals from EPC contractors for the project exceeded the original proposed budget for the reactor and balance of plant by 50% of estimates. Through negotiation of warranties, payment schedule, timelines and cost engineering, the project budget for the electrolyzer, reactor, balance of plant and civil works was brought to within +15% of the proposed budget. In addition, several small functionalities were removed from the balance of plant to save on costs (full weatherization, some automation, foam protection redundancy and nutrient recovery system). These reductions in scope of supply did not impact overall timing or system delivery, but increased the amount of manpower required for normal system operations. Time impact: 6 weeks delay due to extended EPC contractor negotiations and cost engineering. Cost increases absorbed by project partners.
- Unforseen costs were incurred related to power panel and transformer design, cabling and 'black box' controller for remote control of Electrolyzers (for frequency control), additional costs for civil works and piping connections required for injection station and mixing tank installation for alignment with adjacent ENZUP project, nitrogen use for pneumatics and Electrolyzer operations, disposal of contaminated soil from construction site excavation and regular waste disposal costs for P2G-BioCat operations. Generally these costs were unknown and would have required prior experience with a nearly identical project, detailed site engineering and site-specific knowledge not available at the time of writing of the project proposal. It is unlikely that additional detailed planning and research would have allowed accurate cost accounting for these issues, but a larger contingency consideration was warranted. Time impact: 2 weeks delay for power panel and power cabling design and installation. Cost increases absorbed by partners.
- Timing of securing equity capital match for the ForskEL grant was longer than anticipated; delays resulted largely from evaluation and resolution of international tax law-related issues and resulted in 12 weeks delay in initiation of detailed engineering.

Technology Risks:

- The P2G-BioCat Plant was affected by insufficient biogas and/or hydrogen supply on several occasions during the commissioning and operations period. No electrical supply interruptions were observed. Supply interruptions were due in part to operational cycles or equipment failures at the site that resulted in the lack of availability of biogas input for the system and in the case of hydrogen, due to post-commissioning challenges with operability and control system integration between the electrolyzers and the SCADA/HMI for the Biocat reactor and balance of plant. These interruptions were due to normal operational interruptions at the site and first of its kind engineering and integration issues between the Electrolyzer control systems and the BioCat reactor control system. Time impact: 8 weeks cumulative delays from commissioning to end of project.

- Major equipment failure within the methanation system, including lethal contamination of the microbial culture did not occur.
- Major equipment failure within the electrolysis system did not occur, though minor equipment failures in the first 4 months after commissioning did occur. These failures are attributed to the experimental nature of Electrolyzer #1, to poor water quality on site and challenges with control system integration (see above). Time impact: contributed to 4 weeks cumulative delays in the first 4 months post commissioning. Costs absorbed by Hydrogenics and Electrochaea.
- Major and minor equipment failures within the balance of plant contributed to the delays in the project. These include failure of flow controllers to function at low flow rates for system startup and low flow system testing, failure of chiller/heat exchanger for the system analytical unit, failure of the flare pressure sensing, and BCU control function, and failure of the primary flare suppression system. Some balance of plant equipment failed to meet design and operational specifications at commissioning but were subsequently addressed and did not constitute failures. While unexpected and inconvenient, the 'first of its kind' nature of the balance of plant provided an environment for misalignments of some system components that resulted in early failures. The majority of equipment failures were remedied by the EPC contractor in a timely fashion. Two exceptions were the chiller/heat exchanger (6 weeks) and the flare (8 months) that required long diagnosis, repair, testing and commissioning cycles and replacement by third parties not under the control of the EPC contractor or the Project Supervisor. The flare and chiller manufacturers were unresponsive and unhelpful in remedying their equipment failing to meet specification and the flare was not fully functional until 3 months after the end of the BioCat project. Actual time lost due to balance of plant issues: 12 weeks cumulative delays and reduced operating flexibiity due to flare issues for most of P2G-BioCat. Costs absorbed by EPC contractor, Project Supervisor and flare manufacturer.
- Failure to produce pipeline-grade product gas was not a performance issue; the system can be operated within the gas product guidelines with the exception of water removal; some limitations in the operating envelope (see above) resulted in reactor performance below grid specification at some set points, but within the design specification for the overall system and compatible with the post reactor membrane polishing unit. No additional time lost due to system or biocatalyst productivity limitations.
- Performance measurements were not effective for 6 weeks due to the failure of the chiller/heat exchanger required for the primary analytic device in the balance of plant. A second analytic system was acquired by Electrochaea for redundancy and to expedite operations. No additional time lost to that identified above. Costs for additional analytic system absorbed by Project Supervisor.

Schedule Risks:

- Unforeseen delays to planned timeline and completion- Negotiation of initial side contracts and accession agreement from one of the partners required 4 months, and 2 additional months were required to negotiate and secure payments agreed under the grant from the same partner; these delays overlapped with other delays but did contribute to overall project delay; no other delays occurred due to project planning for regulatory, permitting and contract completion. Time impact: 4 months

- Supplier failure: late electrolyzer delivery – Electrolyzer #2 was delayed 4 weeks from the original plan, but since one electrolyzer was on site and functional this had no impact on the overall project timing.
- Supplier failure: no late bioreactor delivery - Bioreactor delivery, assembly and commissisioning were on time by EPC contractor

Regulatory Risks:

- Additional permit required to operate plant – several additional permits than planned were required to allow plant operation, but all permissions were acquired within the anticipated timeframe. As a first of its kind facility, and with processes unknown to the local safety and regulatory authorities, the final jurisdiction for temporary permits for start up and commissioning and for approval for final operations needed to be negotiated among the local authorities after review of the Plant HAZOP plan and PID review. Learnings will provide guidance for any future plants in Denmark.

Risks related to Integration between project participants:

- As anticipated, the integration between participants was the most challenging project management issue. Major issues included two and three party agreements for services, warranties and scope of services that could not be negotiated prior to the approval of funding for the program. These negotiations and definition of exact scope of work were generally handled well among the Partners and also with third party vendors responsible for civil works, and system tie – ins and testing.

- Facility tie-ins and system integration resulted in several delays. The primary issues related to integration were i) water quality, evaluated at the time of site assessment had changed and technical water quality on site had degraded by the time the BioCat system was installed and tested. On start up the technical water quickly fouled the water purification systems for the Electrolyzers and resulted in 2 weeks delay before a water purification system could be installed to pretreat water for the Electrolyzers. Time impact: 2 weeks, Costs for the water system absorbed by Partners; ii) coordinating and executing the design, acquisition, installation and testing of the black box for remote control of the Electrolyzers for load following and working in the regulated power markets required 12 weeks and interactions with the power service vendor, NEAS Energy, Dong, Electrochaea, Zeton, and Hydrogenics. The remote control system is functional, but was not tested for real controlling operations prior to the end of the BioCat project. Cost for the system design and implementation borne by Partners; iii) the largest risk impact on the project was the failure of the adjacent ENZUP project, a CO_2 capture system to be executed among the site host and other partners. The ENZUP project was to provide CO_2 for methanation to P2G BioCat. Due to unforeseen circumstances related to a patent dispute that arose late in the ENZUP program, the project was abandoned. As a result, all of the interconnects and tie-ins planned and under construction between ENZUP and BioCat were not directly useful for delivery of CO2. HMN (a partner in both projects) and Electrochaea worked to salvage and redesign the connections to the injection station, and system interconnects so that HMN and the site could provide Electrochaea with raw biogas for use in the BioCat reactor. As a result, the BioCat system has been operated solely on raw biogas for the methanation of the CO2 fraction in biogas into methane. At present the BioCat system is effectively upgrading the biogas by converting the CO2 fraction into methane and delivering grid quality gas, except for the water content. Additional costs to Partners were accrued due to this change in the project. These included additional design and piping connections and the requirement for Electrochaea to install an H2S removal system and additional oxygen detection equipment to accommodate biogas and to remove the H2S from the reactor product gas for grid injection. Since high H2S concentrations (from the feed biogas) result in H2S concentrations in excess of the specification for Electrochaea's post column gas polishing and dewatering unit, alternatives for both dewatering and H2S removal have been installed in the BioCat system. These improvements were completed prior to the end of BioCat and the gas quality analytics for Electrochaea and HMN confirm the gas quality product from the reactor. No time delay for the overall operational testing of BioCat resulted from the ENZUP failure. However, the use of CO2 as a gas input and the actual injection of gas onto the grid have been delayed to the next phase of BioCat. Costs for system modifications to the system interconnects were borne by Partners; iv) Integration and control of the heat exchange interconnect between the site and BioCat was not well designed or executed (by a third party engineering firm), and as a result the frequent absence of cooling capacity required unplanned shut down or delay of BioCat operations or system testing on numerous occasions. This issue persists and will be addressed in the BioCat continuation. Time impact: 4 weeks, overlapping with other interruption issues; cost borne by the host site and Project Supervisor have not mitigated this problem, which persists and will be addressed in the BioCat continuation.

- Inability to test gas injection into grid- this goal was not reached during the project due to the failure of the ENZUP project (see above), resulting in the absence of a dewatering and H2S removal system for the product gas during the project period. Gas quality, except for routine water removal is aligned with biogas feedgas to BioCat and producing gas acceptable for grid delivery. In addition, physical changes from the original design were required to interconnect to the injection station and and gas quality monitoring system. These modifications are now in place. A second reason for the failure to inject gas onto the grid was a regulatory barrier that the execution of BioCat was instrumental in resolving. In order to inject any gas product onto the Danish grid, the product is required to meet compositional specifications AND must have an accepted product definition and designation to allow entry into the Energinet system. Since BioCat is the first biomethanation system on the Danish gas grid, prior to this project there was no official designation for the gas product from BioCat, no certification of the gas composition, no agreed method for its measurement and no agreed product pricing, or qualification in the Danish tariff and regulatory scheme. The product qualification, product identification, and agreements among Energinet, HMN and Electrochaea for the measurement and certification of the gas product, now designated as "synthetic biomethane" required the evaluation of data from the first 6 months of BioCat operation, followed by agreement among the parties on contract terms for both connection and injection agreements for the delivery of "synthetic biomethane". These efforts concluded after the end of the Biocat project. This exercise has established the precedent for synthetic biomethane production, measurement, and injection and lays the ground work for all future projects, including the extension of BioCat. While this process for product designation and certification was contemplated, the exact market conditions and regulatory framework during BioCat were not knowable at the time of writing the Project Proposal. Time delay: grid injection is pushed to the next phase of BioCat. Cost impacts for system changes, negotiations and administrative work for new product designation were borne by Energinet and Partners.

Program management risks: Electrochaea and its contractors and vendors used standard project management protocols including appropriate cost and time controlling to manage and control all activities. The Steering Committee and key members of the consortium provided timely input for reports, were available for problem solving and contributed to the successful resolution of the issues and challenges that emerged during the project. Fernando Keuchen, Dominic Hofstetter and Mich Hein provided overall project management oversight during the project. DH was the initial project manager, was replaced by FK after DH left Electrochaea and MH replaced FK when FK left Electrochaea.

1.5 Project results and dissemination of results

Figure 1.1 Photograph of P2G BioCat Plant on BIOFOS site in Avedøre, Kanalhommen 28

The BioCat plant was erected on the BIOFOS wastewater treatment site in Avedøre between November 2015 and March of 2016. Pictured in Figure 1.1, the system includes the 9m tall BioCat reactor in a 12m tall frame, a flare, balance of plant skid, two electrolyzers, each in 40ft containers, a 20ft container for power panels and distribution and a 20ft control room contatainer with the SCADA/HMI system, power distribution panel for the balance of plant and gas analyser.

The BioCat P2G system is a commercial-scale 1MW capacity power-to-gas facility connected to both power and gas grids,providing direct grid interconnection from power to gas. The system operated for 8 months during the project, including commissioning. During the project, the system used 42,193 Nm^3 biogas, 170 m^3 water and 708,215 kWh electricity for system operations and to produce 129,290 Nm^3 hydrogen for methanation of ~16,000 Nm^3 CO_2 from the the biogas and making available ~15,000 Nm^3 renewable methane and 85,000kWh heat for use at Avedøre's facility. The system operated at variable loads and was used intermittently through 3 seasons until December 22, 2016.

The BioCat system is located at the Northwest corner of the BIOFOS wastewater treatment site in Avedøre, isolated from the BIOFOS operations and offices, and contains three ATEX zones defined by the hydrogen and methane delivery delivery lines, reactor and gas handling system (See figure 1.2 for site layout view).

The relatively short operating period planned in the original project for the P2G-BioCat plant at Avedøre has provided sufficient information to confirm the basic operating parameters and

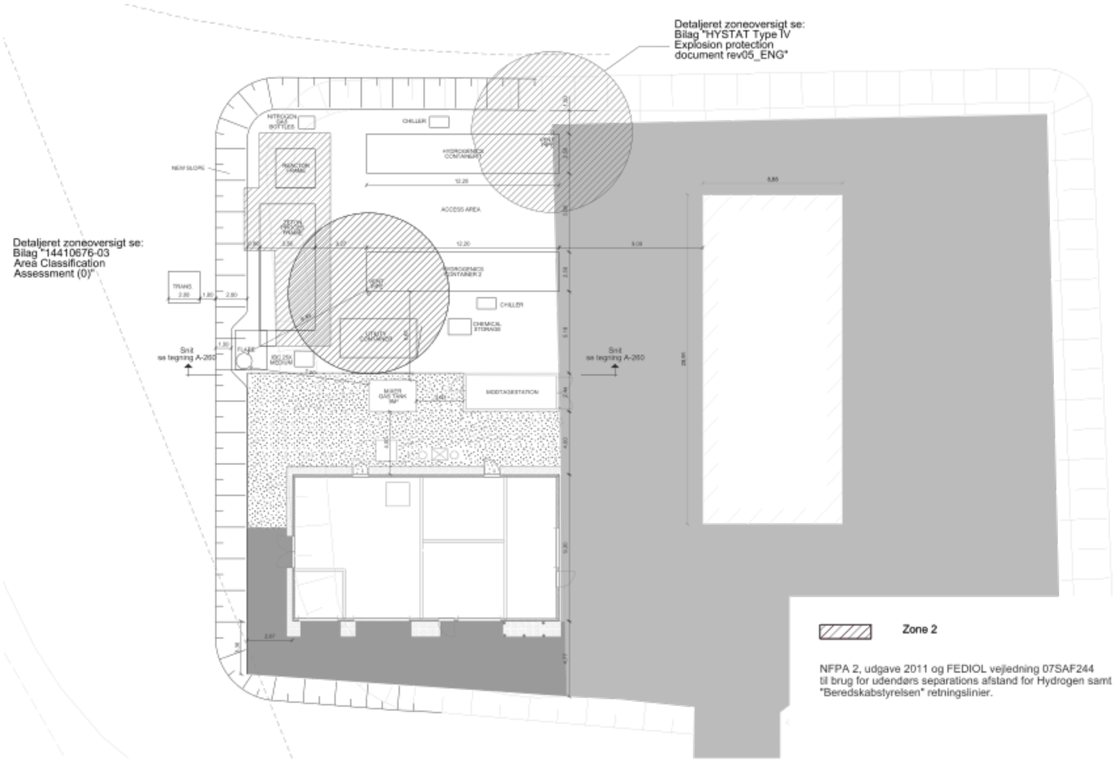


Figure 1.2 Layout of BIOFOS site in Avedøre, Kanalhommen 28, showing ATEX zones for electrolyzers, balance of plant and reactor tower

economics of Power-to-Gas deployment in Demark and elsewhere. In addition, the initial results provide a contractual framework and a fully operational facility for continued operation of the BioCat facility at Avedøre.

The approved total budget for the project was 55,883,326 DKK and the actual project costs were 60,005,811 DKK and the grant financing was 27,597,902 as per the approved budget.

1.5.1 Results Overview

One key result of the project is a plan for continued operation of the facility to demonstrate this promising business opportunity, incrementally improve the technical and economic performance of the system, and provide a demonstration site for Energinet, academic institutions and future customers and partners. Additional funding is sought for this continued development and analysis.

The major results of the project are:

- Design, construction, integration into the BIOFOS wastewater treatment site, physical connection to the gas grid and current operation of a 1MW biological methanation system – *the system is operating since April 2016*

- Upgrading of carbon dioxide to grid quality gas, using raw biogas from the anaerobic digester at an operating wastewater treatment plant – *gas product quality is acceptable*

- Demonstration of continuous or intermittent operations producing grid quality gas consistent with market conditions for power availability and pricing – *the system is flexible and can operate in market conditions*

- Completion of the regulatory and certification processes providing a template for future plant construction and operation, environmental impact assessments, safety approval, waste disposal and gas product life cycle analysis (Carbon footprint) and physical injection onto the Danish gas grid – *regulatory and legal barriers for the Danish market are identified and addressed*

- Verification of actual costs, techno-economic factors impacting commercial implementation of Power-to-Gas solutions in Denmark, including contract structures, pricing mechanisms and predictive models for several business opportunities in Denmark and elsewhere – *investors, system operators, customers and partners can evaluate economics and value to the Energy system*

- Electrochaea has expanded its team on site from 2 to 3 personnel during the project, and plans to add one more person. The facility now serves as a show case for visitors from Denmark investigating P2G and from around the globe. We have hosted visitors from many countries in the EU, from Japan, China, Singapore, North Americal, South America and Africa. – *business and public interest in Power to Gas is growing and showcased at BioCat*

The combined efforts undertaken by the Consortium in the P2G-BioCat project have allowed Energinet.dk and the P2G-BioCat project partners to understand the biomethanation system, its integration with an electrolyzer and the operating constraints and business opportunities in the context of Denmark's energy system. We have further provided an initial assessment and useful tools to evaluate the market benefits of deploying power-to-gas in Energinet.dk's service territory, as well as other EU and worldwide markets.

1.5.2 System Installation

The overall BioCat system design was generated by Electrochaea, with detailed engineering and construction services provided by Zeton NV, from Enschede, NL. The system was constructed in Enscheda and delivered on site in two skids and assembled in one day, and mounted on pre poured concrete pads supported by concrete pilings. The reactor agitator was delivered separately and installed on the same day as erection and mounting of the reactor tower and balance of plant. Subsequent plumbing, wiring, tubing connections, electrolyzer delivery hookup, power connections, signals and control testing, analytics calibration, plumbing and site acceptance testing required an additional 10 weeks on site.

The BioCat process flow diagram (Figure 1.3) provides a high level view of the system as currently installed. The reactor operating envelope is 4 to 9 barg and is adapted to be used with either CO_2 or methane as the carbon dioxide source. The original system design was predicated on using CO_2 feed gas, but with capabilities for biogas. Since the composition of the biogas is not constant, and often contains high levels of H2S, and oxygen, three additional components were added to the system (not included in the BioCat budget) to enable more flexible operation (shown in red boxes in Figure 1.3):

- Pre-compression H2S removal system to eliminate bulk H2S and some oxygen from the input gas prior to compression and injection into the reactor
- Post column H2S removal to remove any H2S leaving the reactor and above allowable limits for grid injection, and
- a final membrane-based gas polishing system has been constructed to remove water and any excess hydrogen from the project gas and to allow a wider envelope of operating conditions, including variable biogas composition, and intermittent operations while still providing grid quality product gas. Any excess hydrogen is recycled to the biogas/ CO_2 compressor for reuse in the reactor. This system will be commissioned in the next phase of BioCat operation.

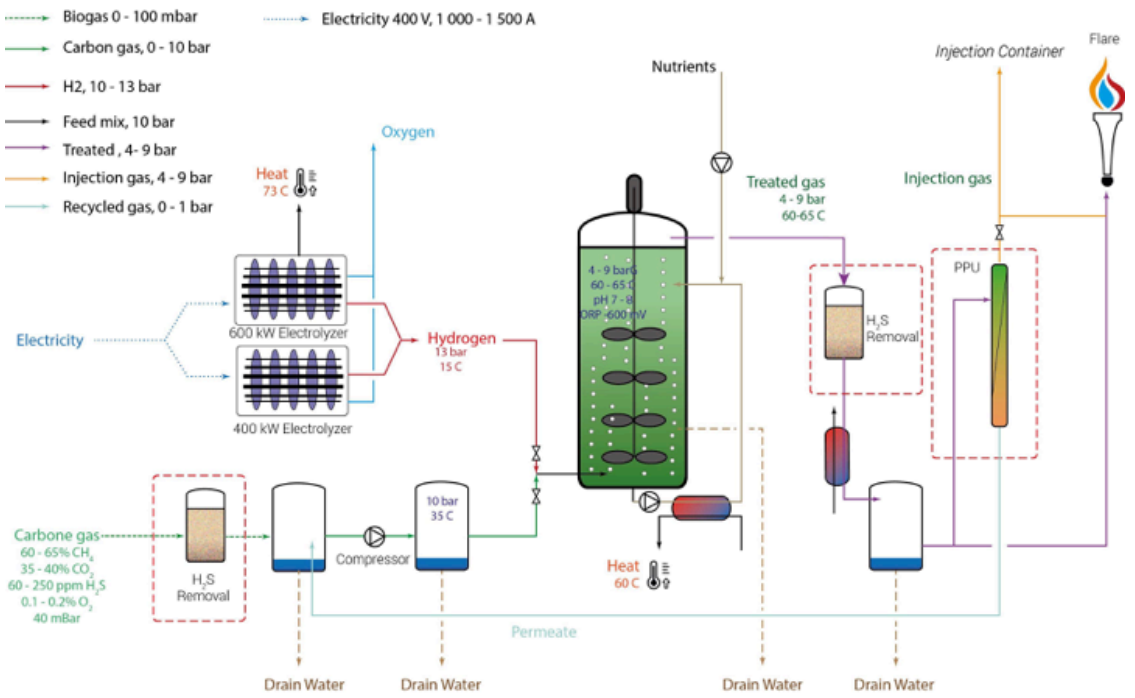
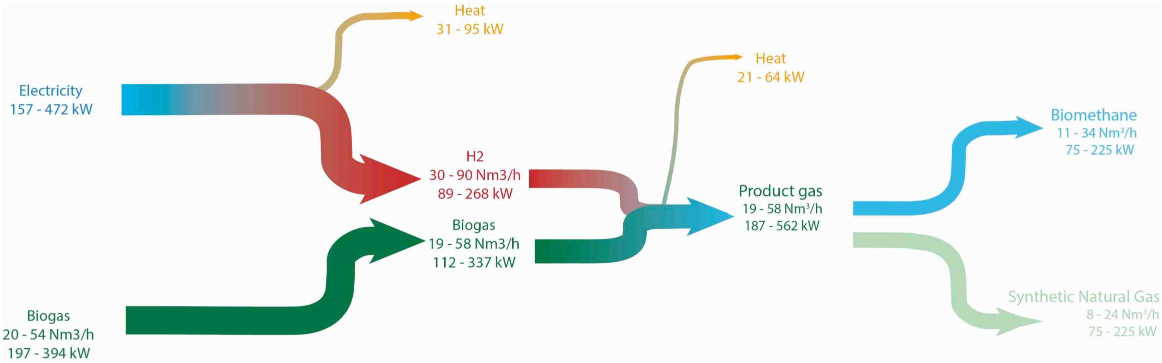


Figure 1.3 High level process flow diagram of P2G BioCat System at Avedøre

In the absence of the final membrane system, the BioCat reactor produces grid quality gas (with the exception water vapor removal). Commercial gas drying systems can remove sufficient water to bring the gas to injection quality prior to commissioning of the membrand polishing unit.

1.5.3 Mass and Energy Balance

The Basic mass and energy relationships of the BioCat Sytem are shown in Figure 1.4, illustrating the maximum and minimum mass and energy flows for the BioCat system in its current configuration of inputs, controls and process limitations.. The system can currently operate with high efficiency conversion from as 30 Nm^3/h hydrogen input and 19 Nm^3/h biogas throughput, and up to 3 fold those flow rates, with hydrogen to carbon dioxide stoichiometric



ratios between 4.02:1 to 4.2:1. This operating envelope is within the design parameters for the system for biogas feed. Whle the system has not yet been tested with CO_2 input, all other reactors of similar type at Electrochaea have superior conversion efficiencies for pure CO_2 input, than for equivalent volumes of biogas, or of CO_2 fractions in biogas. This superior conversion for CO_2 input gas is largely due to the increased partial pressure and resuling improved mass transfer of reactive gases from gas to liquid phases. In short, it is fully expected that the BioCat system will perform better with CO_2 input than currently observed for biogas.

The net volumetric flow of biogas into the system and flow of product methane out of the system are nearly identical when the system is operating at high conversion efficiency and the hydrogen: carbon dioxide gas stoichiometry is near 4.0:1, and since deminimus amounts of carbon are assimilated by the biological catalyst. At BioCat heat from the exothermic methanation reaction is captured for use at the wastewater treatment plant, but heat from electrolysis is dissipated to the atmosphere. In the second phase of BioCat, we propose to combine the electrolyzer and reactor heat recovery, to delivery more thermal energy to the site and improve the overall system energy use efficiency. This would be an expected commercial design objective, to achieve optimal energy use efficiency from the renewable energy

Figure 1.4 P2G BioCat System Mass and Energy Balance

inputs and would provide direct linkage and optimal distribution of energy among for power, gas and heating grids at one site.

1.5.4 Operations and Testing – System Performance

Despite the high frequency of operational interruptions due to equipment or signal malfunctions during the system testing and set up in the first 8 months of operations, the system has been operated continuously for several 100hour campaigns and through normal 5 and 7 day operations with on/off cycles based on normal working hours. Normal operating conditions are 63C reactor temperature, at 7.5 to 8.0barg headspace pressure. Since the water column in the reactor is 8m in height, the system pressure at the bottom of the reactor, where gas injection occurs in approximately 1 barg higher than the head pressure.

The normal and interrupted operations of BioCat in the first 8 months have allowed evaluation of thousands of on/off cycles, with varying "off" conditions, followed by return to normal conversion at 63C. Off conditions include warm "ready" mode, where the reactor is kept within 10C of its operating temperature, "cold" ready mode where the reactor is allowed to cool without heating for 2 to 3 days before restarting (typical reactor temperatures reach 30-40C), complete system shut down to ambient temperature (-1). In all cases the biocatalyst is able to recover to catalytic rates sufficient to produce CO_2 at conversion rates higher than 95%.

Changes in conversion rates and variation in the health of the biocatalyst are sufficiently similar to the biocatalyst behavior in laboratory reactors, that basic rules for system management, nutrient feeding, gas flow rates, mixing energy and volumetric productivity can be extrapolated from laboratory reactor experiences. Likewise, new observations in the BioCat system could be replicated in smaller reactors at Electrochaea's Munich facility. For this reason, the basic system control cycles, reaction times, impact of nutrient feeding and mixing energy were well predicted from laboratory and smaller scale demonstrations. As a result of this similarity in behavior, the initial control cycle planning, operating set points and system performance were well predicted and few changes were required in the control system or physical components of the system to achieve predicted results.

A sample and typical operating cycle is shown in Figure 1.5. In this example, the system was shut down for 2.5h, with no reactor heating and restarted with an average biogas flow of 33.1 Nm^3/h, and hydrogen flow of 53.4 Nm^3/h. Reactor temperature did not drop below 60C during the off period (no additional heating during off period). Durng the shutdown period, the reactor pressure was maintained with a small amount of hydrogen supply, so that any CO_2 in the reactor column at the time of shut down is converted to methane. Since this results in a decrease in volume of the reactive gases, more hydrogen is provided to the system to maintain reacator pressure (~7.5 barg). This leaves a small plug of hydrogen rich gas in the reactor column and reduces the methane concentration in the head space, as shown in Figure 1.5. Under commercial operations with frequent start/stop cycles, the system is designed to maintain head pressure with methane gas, rather than hydrogen. In the BioCat studies we are using hydrogen for pressure regulation in order better understand the reactor and biocatalyst dynamics.

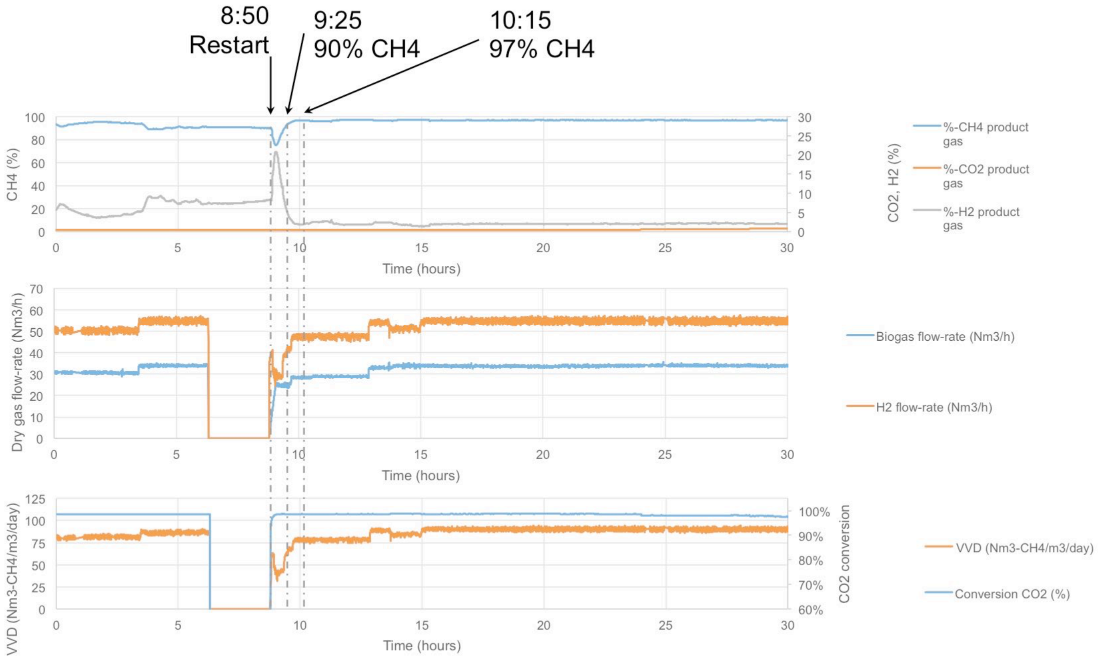


Figure 1.5 P2G BioCat System Stop/ Restart Dynamics and continuous operatons

After restart, conversion immediately resumes and product gas reaches grid quality within minutes. Since the hydrogen in the reactor column has no available CO_2 for reaction,the newly produced methane forces the higher hydrogen concentration gas from the reactor column and head space and the system is purged in ~30 minutes, as higher quality gas flows through the system. It is important to not that the gas analysis shown in Figure 1.5 is conducted well downstream of the reactor column, and some of the time lag is due to system purging, not biocatalyst response time. The post column membrane system is designed to remove up to 20% hydrogen from the product gas so that grid injection can begin within minutes of restart.

After restart the system operates stably for many hours to days. In the example in Figure 1.5, the gas quality was 97% methane, hydrogen 2% and CO_2 less than 1%. Space velocity of the system was approximately 85 VVD on the basis of methane production, and biogas input composition was approximately 37% CO2 and 63% methane.

1.5.5 Life Cycle analysis

As part of the BioCat project objectives, AUDI, on behalf of the project, engaged in a preliminary Life Cycle Analysis of Power-2-Gas for a BioCat biomethanation system in a waste water environment using our preliminary data, or projected data where no relevant preliminary data were available. The Life Cycle Analysis is contained in Annex 1 of this final report.

This LCA study is focused on representing the special case of the coupling between a methanation plant and a wastewater treatment plant, where CO_2 (or biogas) is supplied by the treatment plant and heat is supplied by the methanation system and returned to the wastewater plant. Though BioCat is currently using only Biogas, CO_2 was contemplated as a carbon source and the study includes projections for the use of CO_2 as a Carbon source, and conservative values for the parasitic energy losses (many savings are possible).

Various other commercially relevant cases are possible where a methanation plant can be included for Carbon Capture, as a biogas upgrading plant, or a power grid regulating system but their assessment by LCA is a complex task beyond the scope of the present study. For any actual commercial application of P2G additional scenarios and a careful selection of the functional unit and the site specific parameters would be required for a relevant LCA.

This study does not have such a large scope and ambition but serves as a preliminary indicator of the contribution of bio methanation to the reduction of Global Warming Potential of our energy consumption and is based on the boundaries defined in Figure 1.6.

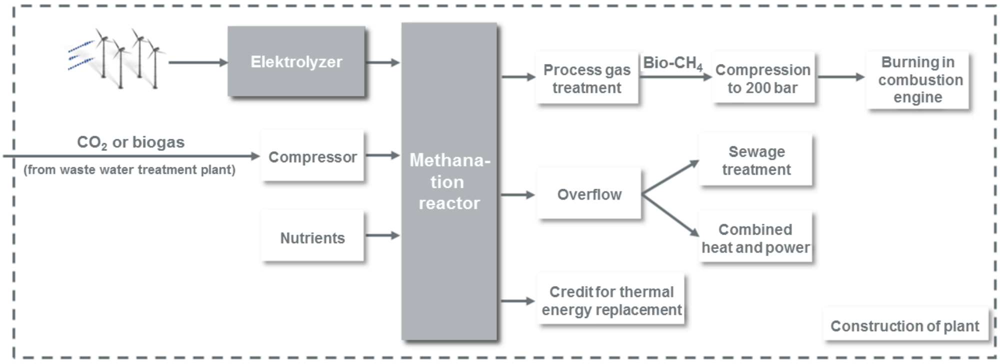


Figure 1.6 LCA system boundaries for evaluation of the P2G BioCat Plant

The basic tenets of the LCA for BioCat were:

- 3000 full-load hours (flh)/ year
- 20 years of plant lifetime
- 240 Nm³ H_2/ h= total capacity of the electrolyzer
- Regular Danish grid mix is used for the electricity needed during standby hours
- Danish wind energy is used for the electricity needed during production hours
- 7 Nm³ H_2/ standby hour = minimum production quantity of the electrolyzer
- 10 kW electricity consumption during standby hours for the methanation part
- Further use of reactor heat in the waste water treatment plant (Therefore more biomethane from the waste water treatment plant is fed into the natural gas grid and a credit for replacing thermal energy from natural gas is given.)

Four different scenarios were addressed in the LCA and the baseline case was selected as a BioCat plant operating with projected data (from current observations) and using pure CO_2 input that would be provided by the host wastewater treatment facility with its own biogas upgrading system, and the final use of the gas would be compressed gas for transportation use. This baseline shows a 75% reduction from equivalent fossil derived natural gas in kg CO_2 equivalents released to the atmosphere per kg biomethane used.

A sensitivity analysis for this scenario indicates that the electrolyzer has the highest impact on the global warming potential (GWP) of the biomethane. Two-thirds of this impact are produced by the standby electricity that is assumed to come from the regular Danish grid mix which in turn is still dominated by fossil energy carriers. The rest of the electrolyzer’s burden results from the construction material and, with a slightly lower impact, by the amount of renewable electricity that is needed to split water into hydrogen and oxygen.

The second largest influence on the GWP of the biomethane of the baseline scenario comes from the thermal energy credit. This credit is given for the replacement of thermal energy from natural gas because the surplus thermal energy of the reactor is used for heating in the waste water treatment plant and allows the plant to feed more biomethane in the natural gas grid.

The third and fourth highest impact on the GWP result from the standby electricity for the BioCat II plant (without electrolyzer) and the energy needed for the compression at the filling station for transportation use. Further details for this baseline scenario, for the LCA boundary conditions and for alternative scenarios are included in Annex 2.

From this preliminary LCA analysis the potential benefit of using P2G for decarbonizing the Danish gas grid is clearly evident. Further, the increasing percentage of renewable power on the Danish power grid and the ability to connect the P2G system into the local heat grid have strong impacts on improving the BWP potential for this technology in Denmark.

1.5.6 Business Model and Market study

Power-to-gas ("P2G") is an innovative and disruptive energy storage solution ideally suited for the Danish energy system. Its key advantage is the unique combination of value propositions that combine to solve multiple challenges posed by Denmark's accelerating transition to a low-carbon economy. Electrochaea along with its partners Hydrogenics, Audi, Energinet.dk (acting in its capacity as the TSO), NEAS Energy, HMN Gashandel, and Insero have executed on the implementation of a novel and scalable biological P2G system under BioCat P2G to address these challenges. The project is the largest biological P2G system in the world and has substantially de-risked the technology, regulatory path and explored relevant business models.

While the technical demonstration of scalable P2G was at the core of this project, the ultimate commercial implementation of this market solution is the major long term objective. To achieve this ultimate objective, two key elements for commercialization have been addressed by the project:

1. Demonstration that the technology is market ready - it can be implemented at commercial scale, with predictable results to produce a grid quality product, and sufficiently simple and reliable for broad implementation.

2. Present a viable business case is evident and achievable in the Danish market that will induce capital nucleation for development of P2G facilities and with sufficient return on investment to compete in the market for other investment opportunities of similar scope.

The capital required to construct and commission BioCat plants can now be projected from the BioCat project, and the first 8 months of operations have provided good insight into the key operating costs for a BioCat system. Estimates from the current project and a detailed analysis of the pricing and availability of power, gas, regulatory services and other derivative value from P2G have been used to generate several business case options for Denmark. In addition, we have identified the critical economic barriers to deploying P2G in Denmark's existing market and engaged with regulators to find ways to remove these barriers.

They key to this market evaluation and business case development is a Market analysis performed by NEAS for the project and presented in Annex 2 and 3. Annex 2 provides an outline for a value maximizing strategy using historical electricity and market price data, operational costs, and assumptions about revenue streams from primary and secondary products of a P2G system. Annex 3 provides a Market analysis focused on future energy system needs and taking into account the Danish energy system trading markets. Combined with a detailed techno-economic model developed for the BioCat P2G system, we have been able to create several viable business models for the Danish Market and provide recommendations for improving market viability to induce the expansion of P2G for energy storage, gas grid and system decarbonization, and linkage to the Danish heat grid. The techno-economic model is a proprietary product of the Project, at present and is being used to identify commercial opportunities in the Danish market.

1.5.6.1 Costs for BioCat

The costs for operating a Power-to-Gas system were evaluated in the BioCat Project (2014-1-12164) over a 9 month period (April 2016 through December 2016). Baseline operating costs for commercial power to gas systems will include labor, amortization of capital, facilities/space rental, maintenance contracts, variable costs for supplies and reagents and the costs for electrical power that is stored in chemical bonds of methane. Costs included in the BioCat evaluation also include expenses for the facility startup and commissioning, system testing and calibration, permitting, certification and safety approvals, reagents, labor and supplies for operations, and power consumption.

Many of the startup costs can be amortized over the assumed lifetime of the plant (e.g. permitting, inspection, certification, safety approvals, initial reagents and supplies). Other operating costs during startup and initial operations (power and other utilities, labor, maintenance) are representative of anticipated future operations.

Power consumption costs for the electrolyzers are the major operating cost during methane production and reflect the energy accessed from the local power grid for conversion and storage in chemical bonds of methane. Since the power price is variable over time, the actual operational profile of the Power-to-Gas system results in variation in the production cost of methane. Other operating costs are relatively fixed for each hour of actual plant operation, and are small in comparison to the power purchase expense.

Capital costs for a commercial Power-to-Gas facility are anticipated to be amortized over 20 years, with replacement costs for electrolyzer components amortized over 7 – 20 years predicated on duty cycle profiles and hours of use. The BioCat project capital costs exceed the predicted costs for a commercial Power-to-Gas facility. The current BioCat facility in Avedøre is a 'first of its kind' project including many first time and site specific engineering costs, optional experimental components and system layout preferences to accommodate safe demonstration and accessability for frequent inspection by operational staff and visitors. For example, ATEX zones for the BioCat system were designed for maximum safety to allow regular access by staff during active operations (Figure 1.2).

Significant capital cost savings are anticipated for future like-sized Power-to-Gas facilities, based on learnings from BioCat and from typical scaling factors for larger size unit operations. These savings are reflected in the cost projections for commercial Power-to-Gas systems discussed later in this report.

1.5.6.2 Power related costs for operating a Power-to-Gas facility in Denmark

Operational costs for a power-to-gas facility are dominated by electrical power costs. Only 3% to 5% of the power consumed in BioCat was used for basic lighting, system standby, computers and auxillary equipment. Since the commissioning of the BioCat Plant in April 2016 the composition of the cost of electricity in the Danish system per MWh, considering the fees and taxes[2] fixed by Energinet.dk are shown in Figure 1.7. Therefore, it is evident that the average market bulk power price based at the synchronized grid area DK2[3] (Eastern Danish Power System) is lower than the additional cost incurred by consumers with a consumption capacity below 100 GWh/year[4].

The composition of additional fees and taxes is explained in Annex 3. However, these additional costs attached to the bulk power price may not lead to a demonstration of the real value of power and can mask the market signals for the value of stored versus used energy. This price masking can impede the development of technologies that provide services to the system. As a consequence, Denmark's goal of being fossil fuel free by 2050 established in the Danish Climate Policy Plan[5] might be difficult to reach without unmasked energy prices or incentives to effectively store the excess amount of intermittent renewable energy generation.

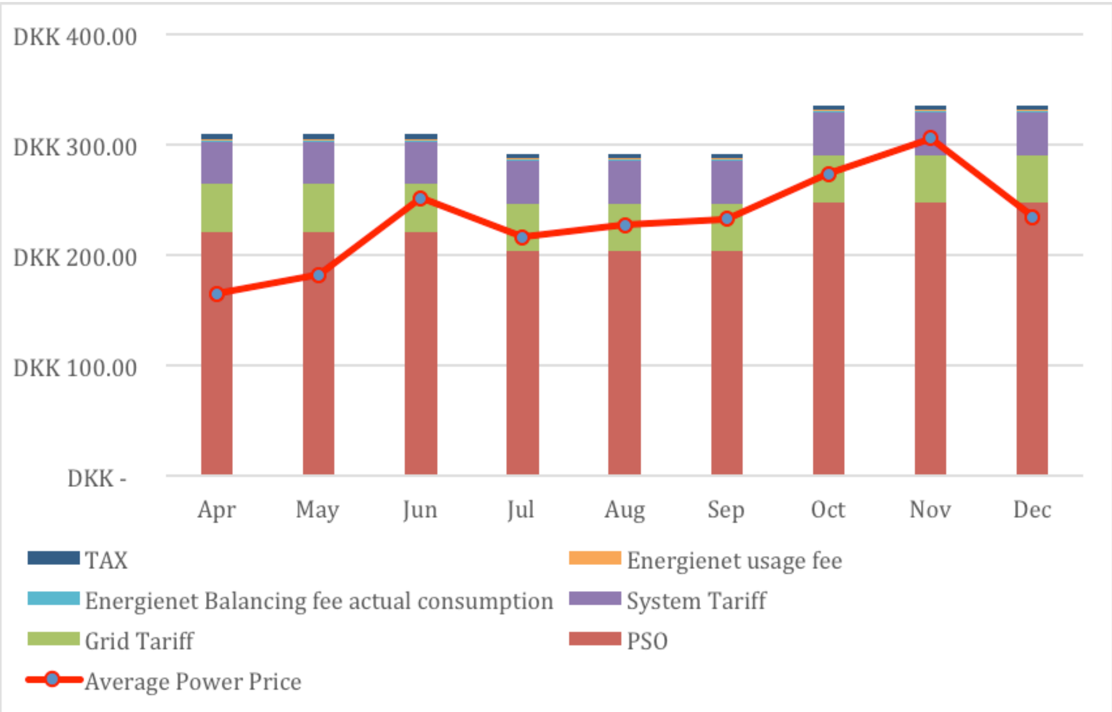


Figure 1.7: Comparison of power price and additional cost/taxes DKK/MWh

Therefore, as seen in Figure 1.7, the highest impact fee related to the power price is the PSO Tariff - for the time of operations of the BioCat Plant in average[6] 97% of the cost of bulk

[2] Electricity Tax is 833 DKK/MWh, however as a VAT registered company consuming the electricity as process, electricity the Tax is compensated except for 4 DKK/MWh (European Union Regulation)

[3] http://www.nordpoolspot.com/Market-data1/Elspot/Area-Prices/ALL1/Monthly/?view=table, accessed on 03.01.2016

[4] http://energinet.dk/EN/El/Engrosmarked/Tariffer-og-priser/Sider/Aktuelle-tariffer-og-gebyrer.aspx accessed on 03.01.2016

power. In other words, for each MWh of Bulk Power, almost the same price is paid for the PSO Tariff. In addition, by comparing the average Bulk Power price to the additional costs (TSO, DSO's and PSO) on average it aggregates to about 133% of the price of power on the Spot Market, constituting a price masking and a barrier to the deployment of storage technologies.

Summarizing, OPEX from the electricity consumption, related to, tariffs, fees and taxes linked to the bulk power price do not reflect the actual of value of power in the system. These additional costs, while important revenue streams for financing power generation, security and delivery can lead to a distortion of economic incentives that reduce the market clarity[7] and limit the capital flows to pursue increasing efficiency and reducing costs for the storage of electricity.

1.5.6.3 Non-power related operating expenses for a Power-To-Gas plant

Power price is not the only operating expense incurred by Power-To-Gas via Biological methanation. The cost of chemicals and nutrients for the biocatalyst and operating the plant have been investigated during the BioCat project. We initially used reagent grade chemicals, as in the laboratory environment, but have tested bulk chemical suppliers and lower purity reagents to reach a viable operational cost of ~ 7,4 DKK per fully operational hour.

One objective of the original BioCat project proposal was to design and install a system for nutrient recovery and recycling. This option was eliminated from the final design for capital cost savings, but from insights gained during the project and additional research relevant to the operation of the BioCat Plant, we believe that for large grid scale P2G facilities a nutrient recycling feature would further reduce the cost of chemicals and nutrients to around 10% of the current expenses. The payback of capital would be less than three years for a plant operating more than 4000 hours per year.

Nevertheless, current chemicals and nutrients costs for the biological methanation process do not pose relevant economical constrains to the deployment of the technology as the cost corresponds to less than 1% of the hourly electricity bill.

1.5.6.4 Overview of the CAPEX for Power-to-Gas in the 10, 20 and 50 MW size

Power-To-Gas via biological methanation benefits from economics of scale due to the facile scalability of the technology. From to the completed design, engineering, construction and commissioning of the BioCat Project, Electrochaea has further developed with its engineering team a cost-down model for larger scale plants. The leverage to reduce CAPEX by scaling the biological methanation Power-To-Gas plant, refining the reactor and balance of plant design based on learnings from BioCat will reduce the time to deploy new plants at lower cost.

5 https://ens.dk/sites/ens.dk/files/Material/file/dkenergymodel.pdf, accessed on 03.01.2017

6 Average price of PSO and Bulk Power from April to December 2016

7 http://www.iea.org/publications/freepublications/publication/Next_Generation_Windand_Solar_PowerFrom_Cost_to_ValueFull_Report.pdf, Accessed on 03.01.2017

Figure 1.8: CAPEX for different MW size P2G plants

CAPEX ESTIMATE SUMMARY	1 MW	10 MW	20 MW	50 MW	
Electrolyzer*	**DKK 5.18**	**DKK 51.80**	**DKK 103.60**	**DKK 259.00**	**MILLION DKK**
Methanation	**DKK 10.90**	**DKK 28.10**	**DKK 36.82**	**DKK 63.54**	
Project Mana-gement	**DKK 2.23**	**DKK 4.51**	**DKK 5.62**	**DKK 7.53**	
Start-up Comis-sioning	**DKK 0.41**	**DKK 1.35**	**DKK 2.00**	**DKK 3.39**	
Contingency	**DKK 0.37**	**DKK 1.11**	**DKK 1.48**	**DKK 2.59**	
Total	**DKK 19.09**	**DKK 86.88**	**DKK 149.52**	**DKK 336.05**	
DKK/KWe	**DKK 18,722**	**DKK 8,436**	**DKK 7,252**	**DKK 6,586**	

*An assumption of linear growing rate of prices for electrolyzers is presented

Based on current information from BioCat and market pricing of components, we have developed CAPEX and installation cost estimates for different sizes of Power-To-Gas plants in the range of 1 to 50MW (Figure 1.8).

As seen in Figure 1.8, Power-To-Gas plant benefit from economics of scale, reducing the CAPEX needed for deploying the technology in bigger operational sizes while providing a better value for the system by providing a lower cost energy storage service.

1.5.6.5 Barriers to the deployment of the technology

Under the current market conditions, the deployment of Power-To-Gas in Denmark is restricted due to the high cost of tariffs and fees that mask , the actual price paid to the producer for electricity. Current market costs for power do not represent the real cost of bulk power, but also include costs for the design and implementation of mechansims to build and to maintain 100% reliability, support infrastructure to avoid curtailment and subsidize new generation capacity. However, these costs limit the entrance of P2G units into the market that can provide the regulating services needed by the system in as explained in Annex 2 and 3. Placing P2G assets behind the meter can avoid many of these costs, but significantly limits deployment options.

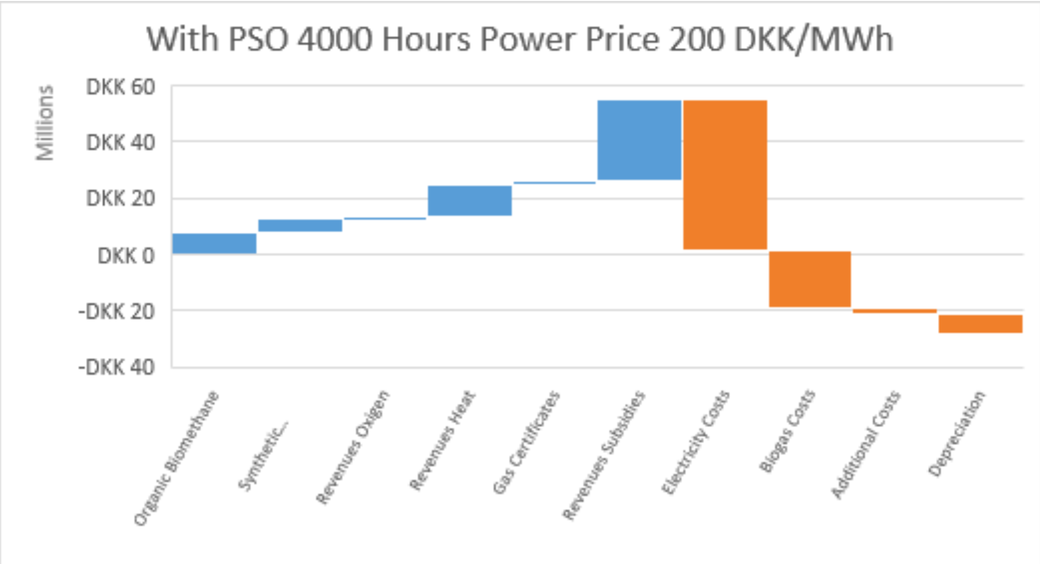
1.5.6.6 Impact of taxation for electricity use (energy tax and grid fees)

The composition and market impact of the taxation and grid fees is explained in Annex 3, while a further clarification of the barrier that PSO tariff poses to the deployment of Power-To-Gas in Denmark is provided here.

The PSO tariff is a measure to promote environmental friendly electricity production, subsidizing wind turbines, biomass plants, solar cells and decentralized Combined Heat and Power (CHP). However, it is an obstacle to further improve the efficiency of the renewable electricity generation assets due to the high cost to be carried by energy storage systems that are not actual energy "users"but rather a medium to link electricity production with storage via another energy carrier.

Taxes tariffs, fees and the cost of electricity production exceed the current value of the combined stored energy and ancillary products and services from a P2G facility, even when actual spot prices for power are low (Figure 1.9). Purchasing power off the grid and deploying Power-To-Gas Plants to manage the electricity system is currently not economically viable.

Figure1.9: Deployment of 20 MW P2G plant business as usual operating 4000 hours/a



1.5.6.7 No support pricing for biomethane production from carbon dioxide

The production and commercial deployment of biomethane from biogas in Denmark reduces the emissions of greenhouse gases from manure, provides renewable gas to substitute fossil fuels and allows the improvement of nitrogen absorption by crops[8]. Strong governmental commitment initiated in 2009 has led to an increase the national production of biomethane.

Currently, the production of biomethane from carbon dioxide is not recognized by the government as a mechanism to achieve decarbonization goals or to store intermittent energy. When biomethane is produced with CO_2 from a biogas input, total emissions of carbon dioxide are abated, increasing by 66% the efficiency of the process. With BioC-Cat we have been able to demonstrate the mass and energy accounting for this process improvement. However, only support for biomethane produced by anerobic digestion is currently backed by subsidies, providing no parallel incentive to further reduce the greenhouse gas emissions from the organic matter disposal process. Similar subsidy schemes for production of methane from CO2 and renewable power would partially overcome high power costs and reduce economic barriers for the deployment of Power-To-Gas technologies.

1.5.6.8 Unfavorable design of the regulating power markets.

Currently, a minimum of 10 MW power capacity is required for submitting bids in the regulating power market in Denmark. This restricts the possibility of small Power-To-Gas units to provide services in the regulating power market because of the need to be pooled with other smaller generation assets. While only available for a limited number of hours per year, the revenues from regulatory services would improve cash flows for P2G operations and increase grid stability.

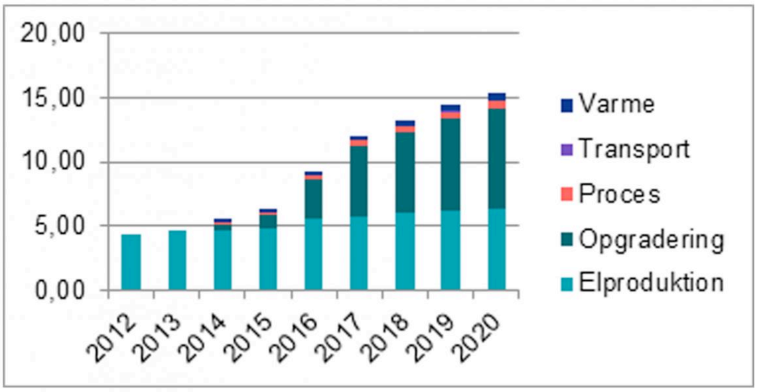
1.5.6.9 Scenario showing a Danish success story

How big does Power-To-Gas deployment need to be in Denmark?

The market potential of deploying Power-To-Gas in Denmark can be calculated depending on the carbon dioxide feedstock base. Biogas is a reasonable starting point since the technology is widely deployed and with the addition of P2G technology additional value is added to the existing biogas value chain, by converting the carbon dioxide present in the biogas mixture to biomethane, eliminating any anthropogenic emissions from the process.

Biogas production in Denmark is based on sewage sludge, agricultural, industrial and landfill gases' as feedstock[9]. In 2014 biogas production reached 1.5 TWh (5.5 PJ) in Denmark or around 4.5% of the natural gas consumption. By 2020 the estimates for biogas production are estimated to be between 3 and 5 TWh (11 – 18 PJ) as seen in Figure 1.10. IF all this biogas were upgraded with Power-To-Gas technology the needed installed capacity will be between 500 and 900 MW of methanization capacity and producing between 3 and 5 TWh biomethane at a capacity factor of 50%.

Figure 1.10: Estimated biogas production in 2020 by use (PJ)[10]



[8] Biogas in Denmark – a potential energy source with benefits for the environment, from http://www.ecocouncil.dk/documents/publikationer/1081-120906-biogas-in-denmark, accessed on 10.01.2016.

[9] Presentation "Biogas Investment & Business Opportunities in Denmark Munich October 25 2016" by Bruno Sander Nielsen, Danish Biogas Association

[10] From Danish Energy Agency, https://ens.dk/ansvarsomraader/bioenergi/produktion-af-biogas, accessed on 12.01.2017

The Danish Energy Agency calculated that for 2050 Denmark the potential of biomethane production could be 11,1 TWh (40 PJ) and if upgraded with hydrogen as Power-To-Gas it could reach up to 18 TWh (65 PJ)[11]. The additional biomethane expected from Power-To-Gas, refers to up to 7 TWh of synthetic methane or an expected installed capacity of around 1.2 GW Power-To-Gas plants with an input of biogas at 50% capacity factor.

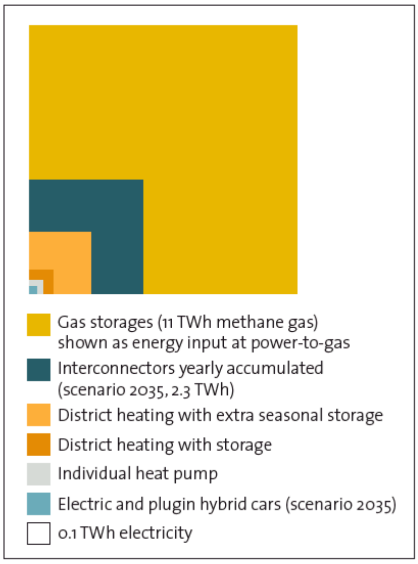


Figure 1.11 Anticipated Storage capacities in the 2035 energy system

Other sources of carbon dioxide can be considered in the deployment of Power-To-Gas in Denmark, including industrial carbon dioxide emissions which in 2014 accounted for 2.5 million tons of the emissions from the energy sector that reached up to 19 million tons[12]. If technologies to capture the carbon dioxide emissions from industrial processes, waste incineration and the energy sector are installed in Denmark, capturing 10% of this emissions as a feedstock for Power-To-Gas could enable the deployment of 5 GW plants with a capacity factor of 50%. Adding up the potential sources of Power-To-Gas as an energy storage solution, Energinet.dk calculated as shown in Figure 1.11 that by 2035 it is possible to have 11TWh of storage capacity coming from Power-To-Gas, reflecting a deployment of the technology as biogas upgrading and carbon dioxide reuse from industrial and energy generation emissions. (Figure 1.11[13])

1.5.6.10 Danish Power price and availability

More than 50% of the gross energy consumption in the Danish electricity sector is currently supplied by renewable energy generation[14]. The impact of the deployment of intermittent generation on the system has an impact on the market power price and volatility. As seen in Figure 1.12, which illustrates the +/- standards deviation in the market price of power in eastern Denmark,the standard deviation range between is 100 and 300 DKK/MWh, implying a high volatility of the power price during the course of 2016.

This high volatility of power price reflects unregulated power production and results in negative impacts to utilities cash flow and cash flow plannning. Capital investments are required

[11] https://ens.dk/sites/ens.dk/files/Basisfremskrivning/energiscenarier_-_analyse_2014_web.pdf, accessed on 09.01.2017

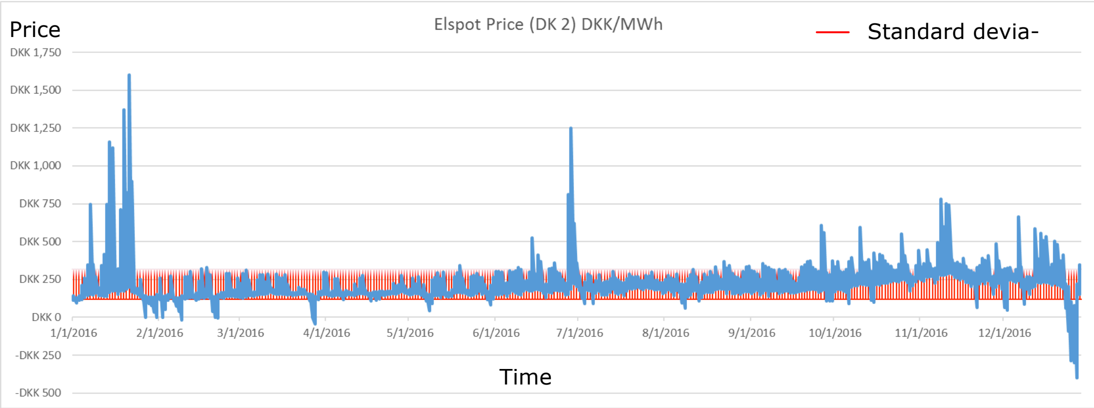
[12] From Energy Statics, Danish Energy Agency, https://ens.dk/sites/ens.dk/files/Statistik/energystatistics2014.pdf, accessed on 10.01.2017

[13] Energy Concept 2030 – Summary, 2015, from https://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/Klimaogmiljo/Energy%20concept%202030%20-%20Summary.pdf, accessed on 09.01.207

[14] Energy Statics 2014, Danish Energy Agency, from https://ens.dk/sites/ens.dk/files/Statistik/energystatistics2014.pdf accessed 11.01.2017

to balance the grid as well as for variable deployment of power generation assets, ending in an high impact on costs to the end use consumer.

Figure 1.12 Power Price DK2 in 2016[15]



As can be seen in Figure 1.12, events in which market price has been negative are happening more frequently reaching as low as -398 DKK/MWh. In addition, prices up to 1598 DKK/MWh were reached. These events provide a snapshot of the potential value to the system of third parties deploying assets to control these supply/demand imbalances. Power-To-Gas has the ability to provide relief to the grid operator by avoiding curtailment or using the stored energy and lowering price volatility and large system management payments.

1.5.6.11 Behind the meter scenario

By October 2016 an installed wind capacity of 6050 MW was in place in the Danish market,. Of this capacity it is expected that around 2230 MW of systems with installed capacity below 1.5 MW will no longer receive subsidies for electricity generation. The end of the subsidy for these generation assets implies they would be able to provide electricity to the market at or slightly above the marginal cost of of maintenance and operation. It is expected that the marginal cost will be around 200 DKK/ MWh[16]. As seen in Figure 1.13, in 2016 events in which the market price of power was below 200DKK/MWh reached 4152 hours by 2016 in the DK2 market. This is nearly 50% of the annual hours of operation.

[15] Data from Energinet.dk market data http://energinet.dk/EN/El/Engrosmarked/Udtraek-af-markedsdata/Sider/default.aspx

[16] Personal Comunication with NEAS Energy

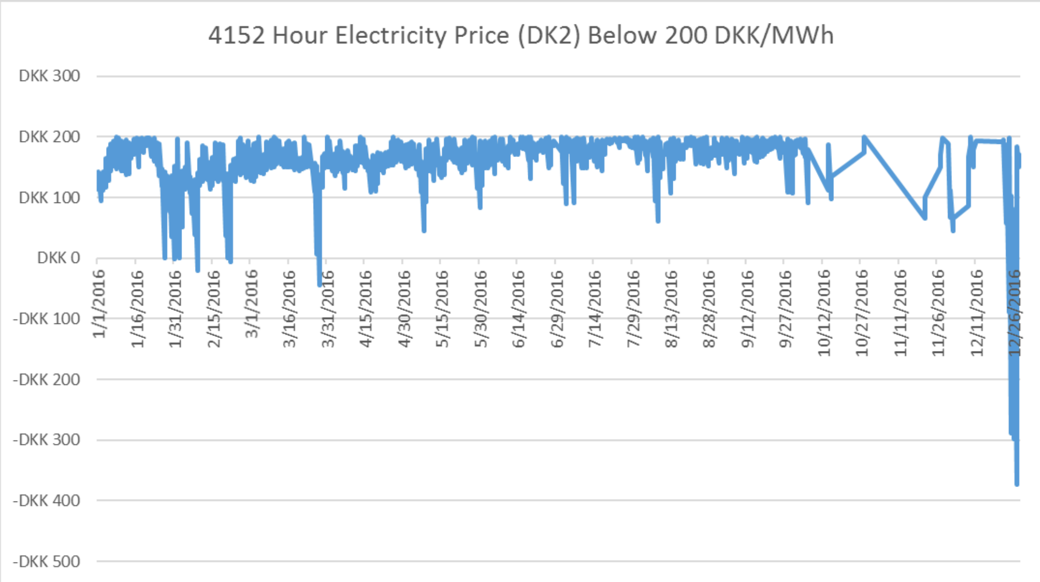


Figure 1.13: Price of Electricity in DK2 below 200 DKK/MWh

The implications of a market power price below 200 DKK/MWh from a system perspective, indicates that owners of wind assets with an overall capacity of around 2230 MW will not be able to offer power to the market at their marginal cost for over 4000 h per year. This power provides an ideal opportunity for the wind owners to engage with Power-To-Gas assets to supply power from their "old" wind parks out of the subsidy scheme to provide power at a fixed price of ~200 DKK/MWh.

Assuming that it is possible to connect a Power-To-Gas plant with these wind mills and a nearby biogas source, viable economic cases will arise for the deployment of the technology as shown in Figure 1.14..

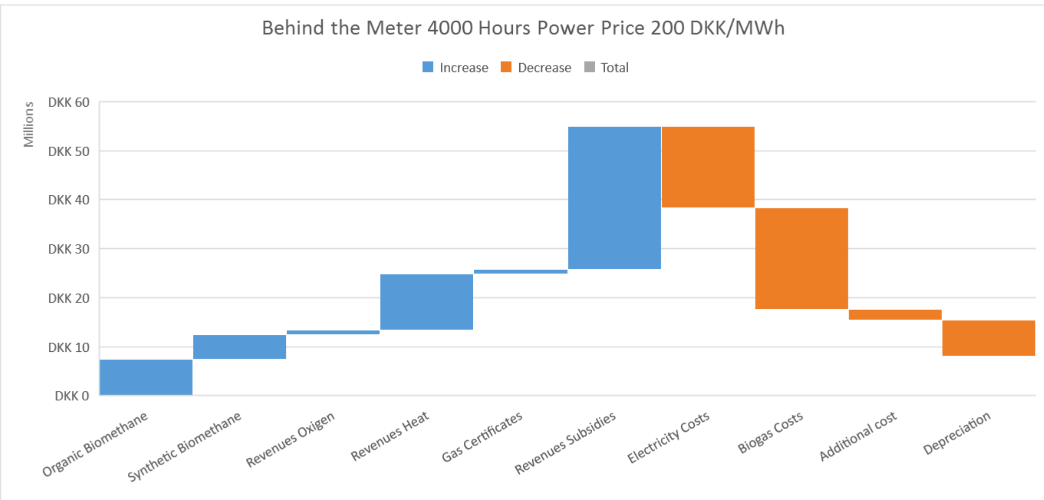


Figure 1.14 Yearly revenues and costs of a 20 MW Power-To-Gas plant operating behind the meter for 4000 hours with a power price of 200 DKK/MWh

Reaching a viable economic scenario for the deployment of a 20 MW Power-To-Gas behind the meter brings the possibility to maintain use of paid off wind assets, and provide benefit to the Danish rate payer. The installed wind capacity expected to no longer receive any subsidies can be further optimized, maintaining the return of capital for Danish utilities and wind mills operators with potential to defer additional capital for new ”on subsidy” wind mills. Second, deploying Power-To-Gas technologies coupled to biogas sources provides the abatement of 8700 tons of carbon dioxide[17] and the replacement of 122 GWh of fossil natural gas reducing Danish dependence on gas exporting countries while improving energy security. Third, the value generation from a Power-To-Gas plant by linking stranded electricity production to the gas and local heating grids ensures that the value remains in Denmark for asset owners and the Danish rate payer.

1.5.6.12 Scenario showing subsidy and tax adjustment with Power-To-Gas

The previous scenario presented a positive economic case for coupling Power-To-Gas with stranded wind mill assets, recognizing a marginal cost for the power, but not paying access or use fees for the power distribution or transmission grids. By doing so, it can be concluded that the taxes and fees associated with grid use are the key economic barrier to deployment of the technology in a grid scale size. Nevertheless, from a system perspective a solution in which the stranded wind mill assets are still connected to the grid but taxation from the electricity side as well as subsidies are modified to provide positive cash flows pr also presents economically viable cases for deploying P2G and storing of energy from the grid system when power prices are sufficiently low.

Providing a product subsidy for carbon dioxide converted to biomethane under the same conditions as upgraded biogas, and revoming the PSO tariff for energy storage applications provides an economically viable case for deploying Power-To-Gas plants fully interconnected to the electricity grid and and biogas source (Figure 1.15).

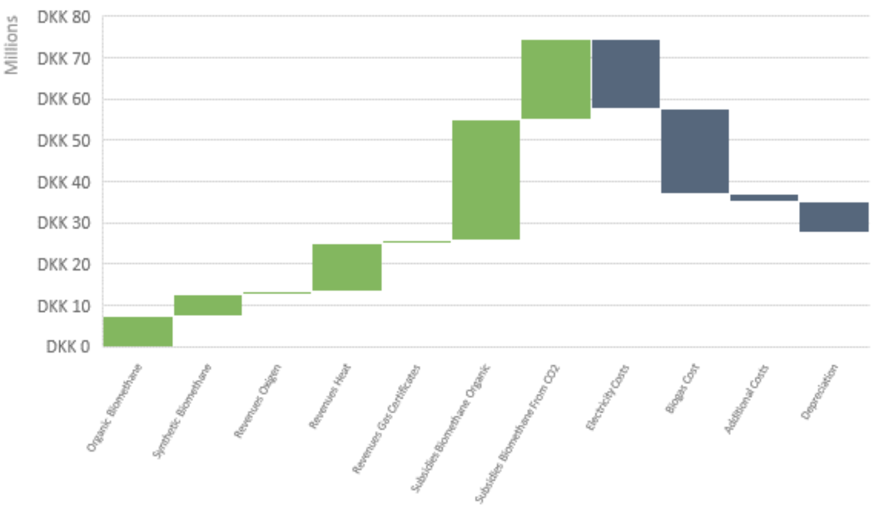


Figure 1.15 Revenues and Costs for a 20 MW Power-To-Gas plant operating 4000 h with a power price of 200 DKK/MWh, tax adjustment and subsidies for biomethane from CO_2

Operating a Power-To-Gas plant during 4000 hours at a price of bulk power of 200 DKK/MWh, DSO and TSO costs included generates positive cash annual cash flow. It is anticipated that the adoption of significant energy storage capacity on the Danish grid would

[17] Assuming a biogas with 60% CH4 and 40% CO2 composition

result in a flattening of the power cost curve, decreasing the volatility of prices and therefore capital cost related to uncertainty on planning by utilities as well as avoidance of curtailment. More hours of lower cost power would be anticipated with increasing penetration of renewable generation, creating greater need and opportunity for energy storage.

1.5.7 Opportunity

Investments in Power-To-Gas at a grid scale size is possible in Denmark. The returns from Power-To-Gas under favorable conditions meet the risk appetite for utility companies. For scenarios, presented in section Figures 1.14 and 1.15 it is expected that the IRR for a biological methanation Power-To-Gas plant would be between 7% and 13% depending on size and annual hours of operations.

The Danish energy market is arguably the lowest carbon market for a developed nation and as outlined in Annex 2 and Annex 3 the market dynamics are well known and mechanisms in place to continue the decarbonization of all three energy grids in Denmark: Power, Gas and Heat. Power-to-Gas using biomethanation could enable this decarbonization and effectively link the three grids.

1.5.8 Dissemination:

The BioCat system has been used effectively for dissemination of both technical and economic information regarding the use of P2G for energy storage and system integration through site visits, citation by third parties and via the Project website which provides updates on progress and events in addition to providing a primer for understanding biological methanation and P2G technologies in general. In June, 2016 a grand opening for the site brought 78 visitors from Denmark and 12 other countries. The project is well cited internationally and was recently the subject of an AP video project that will be distributed to 270 of AP's worldwide affiliates. We are still evaluating the first 8 months of data and are confident that publications describing the project results will follow.

1.6 Utilization of project results

Each of the project participants has a path to benefit from the BioCat project, through the enablement of commercial roll out of the technology or their component of the Project. Insero business services has extended their footprint into the biofuels and biogas sector; AUDI has secured a potential fuel source for their growing fleet of G-Tron renewable gas vehicles and adopted biological methanation as a showcase technology for their development team in Ingolstadt; BIOFOS has integrated a new energy savings technology and enabled a new revenue stream from their Avedøre facility and bridged the BioCat project into participation in the Horizon 2020 Powerstep project; Hydrogenics has used BioCat as a test bed for their MW electrolyzer scale up, and power-to-gas offerings; HMN has secured a new source of renewable gas for their gas business, NEAS energy has developed new potential trading strategies and helped create a future market for possible load-responsive power assets for grid balancing, and Electrochaea has created a showcase system for its potential customers and investors, has initiated 3 additional projects based on proof of concept from BioCat and used the site to secure customer and partner relationships. All of the parties have benefited from positive press and public exposure during BioCat's execution. Most of the BioCat partners anticipate some commercial benefit from the project or from the developments that will flow from it. Nearly all of the partners have used the site as a showcase for the project and their roles.

Important uses of the project results are still evolving,since the project has only concluded 90 days ago. Data is still being analysed and the system is still operating after the end of Biocat. The project and its key uses to date have been:

- The Electrochaea business plan and economic modelling have been updated with the cases presented in this report. In addition, the work at BioCat and in the Danish market has helped us develop a robust techno-economic model to assist in evaluating commercial opportunities in many markets. The Company is actively seeking commercial scale opportunities in Denmark and elsewhere based on the utility of this model and our results at Avedøre.

- Electrochaea has hosted potential partners or customers on the BioCat site from North America, Japan, China, Africa, South America as well as many European countries. We have learned from these visitors that the biological methanation systems productivity, robusteness, simplicity and ability to be modulated on/off at will distinguish biological methanation from chemical methanation.

- To our knowledge no patents have been filed based on project results, but Electrochaea is reviewing 8 months of data from BioCat and anticipates that at least one highly visible publication will result.

- Several of the findings from the commissioning and system shake out have led to new insights into system control, design and automation. These learnings have informed the design and execution of our next projects. While this information is technically intellectual property, it may not be appropriate subject matter for patent prosecution. It is possible that from the review and analysis of data, now ongoing, that discoveries or inventions will result and patent applications will be filed. Since BioCat is continuing operations, it is likely more inventive work will be forthcoming in the next phase of BioCat.

- The execution of BioCat did not involve any academic institutions so there was little direct or planned knowledge transfer to academic institutions. Many academic scientists have visited the facility and with the follow on funding requested for continuation of BioCat we have proposed a research program in concert with DTU. We anticipate there will be significant knowledge transfer in this continuation.

- The implications of the insights gained from the BioCat Project present a strong case for the deployment of Power-To-Gas technology in Denmark at a grid-scale size, and for regulatory changes that will encourage the flow of capital to this enterprise. Electrochaea has engaged with Energinet and other Danish government entities involved in review of taxation and subsidies in the energy system and presented realistic business cases to demonstrate the current barriers, opporunities and inherent value in deploying the gas grid for energy storage. For the future of the technology development, this may be the most important use of the project results: candid communication of the economic barriers to renewable energy storage in the Danish market.

1.7 Project conclusion and perspective

The BioCat P2G project demonstrates a new and powerful option for the Danish energy system, gas providers, energy traders, waste water treatment facilities, other biogas producers and Energinet.dk by pioneering the large scale deployment of a proprietary and flexible P2G system. The project has demonstrated a technical and economic path forward to capture value from the growing supply of intermittent and renewable power to the Danish energy system. The characteristics of P2G with biological methanation effectively allows full integration of intermittent renewable power into the heat and gas grids to capture, store and deploy renewable energy resources for optimum benefit. Each of these grids distributes between 35 and 50TWh of energy to customers each year. Power-to-gas provides an avenue to accelerate the decarbonization and linkage of these three grids to reach the goal of a carbon free energy sector.

The project is a first step, but with execution at 1MW, opens the door to truly grid scale energy storage and grid integration. There are no foreseeable technology barriers to implementation, and costs for both capital and operating components of the system are expected to decrease. The immediate barriers to market entry are largely regulatory in nature and the data and results provided herein should be helpful in guiding regulatory evolution to enable this market sector.

The Danish energy sector, workforce and economy are well suited to deployment and scale up of this solution for energy storage and carbon mitigation. Denmark already has as leadership position in biological methanation and power-to-gas implementation by virtue of the BioCat project and research at Aarhus University and DTU. Continued progress at BioCat should assist in maintaining that role in worldwide markets.

Power-to-gas is an innovative and disruptive energy storage solution ideally suited for the Danish energy system. Its key advantage is the unique combination of value propositions that combine to solve multiple challenges posed by Denmark’s accelerating transition to a low-carbon economy. Electrochaea along with its partners Hydrogenics, Audi, Energinet.dk (acting in its capacity as the TSO), NEAS Energy, HMN Gashandel, and Insero have executed on the implementation of a novel and scalable biological P2G system under BioCat P2G to address these challenges. The project is the largest biological P2G system in the world and has substantially de-risked the technology, regulatory path and business models.

The current barriers to deploying P2G in Denmark are economic and regulatory. The actual price of power generation in excess of demand is masked by tariffs, fees and taxes and the value of the ‘synthetic biomethane’ is uncertain and currently disadvantaged to the value of biogas which is supported by a subsidy. Capital costs for a P2G system are reasonable, anticipated to be 75mio DKK for an integrated electrolysis/biomethanation that could store up to 60 GWh energy if operating at 4000h per year.

The system-wide benefits of P2G are without precedent in the field of energy storage and system integration. By storing low-cost or stranded electricity as methane in the existing natural gas infrastructure, P2G offers practically unlimited storage capacity and "charging" durations in the nearly 45TWh of energy storage capacity in Denmark's gas grid, the largest energy storage reservoir available to Denmark. Other unique features include the ability to provide power grid balancing services, the dissociation of charging and discharging in terms of timing and power rating, the ability for geographic energy transmission via pipelines, high scalability (100 kW to >50 MW), and the ability to connect P2G units to both the transmission and distribution grids. A robust deployment of P2G in Denmark could help integrate the nation's modern and well-distributed electricity, gas, and heat grids.

The most promising opportunities are to access renewable power "behind" the meter, such as for onshore wind assets that have exceeded the subsidy period, and large scale anaerobic digestion facilities (wastewater treatment, or agricultural) where biogas or CO2 from biogas upgrading is available and the exothermic heat of reaction from the methanantion process and electrolyzer can be used on site.

The key innovations in this project: use of a biological catalyst in a pressurized commercial scale reactor, intermittent use of the system to respond to available power, and resiliency of the biocatalyst to raw biogas, contaminants and a challenging duty cycle were all well demonstrated. The biocatalyst performed well under these conditions, with raw biogas as the carbon dioxide source and required a single biocatalyst inoculation at the start of the project, with no supplemental addition or replacement. The reactor and biological catalyst in BioCat are capable of producing grid quality gas - greater than 97% methane, <2% Hydrogen, <1% CO_2, and <5ppm H_2S in the product gas at Pressure greater than 6 barg. The only additional required step for grid injection is drying to remove water vapor.

The BioCat system has been used effectively for dissemination of both technical and economic information regarding the use of P2G for energy storage and system integration through site visits, citation by third parties and via the Project website which provides updates on progress and events in addition to providing a primer for understanding biological methanation and P2G technologies in general.

Annex:

Project Website: BioCat-Project.com

Annex 1: Life Cycle Analysis (AUDI)

Annex 2: Development of a value maximizing trading strategy (NEAS Energy)

Annex 3: Market Analysis Report for Denmark (NEAS Energy)