Biocat Roslev – Project 1

Final Report

05.08.2020

Project identification	EUDP J.nr. 64018-0064
Funding program	Energiteknologisk Udviklings- og Demonstrations Program (EUDP)
Project managing company	Biocat Roslev ApS Chr. M. Oestergaards Vej 4A 8700 Horsens
Project partners	Biocas Roslev ApS (BCR) Aalborg University, Dpt of Development and Planning (AAU-Dev) Aalborg University, Dpt of Energy Technology (AAU-Tech) Brintbranchen Centrica Energy Trading A/S (formerly NEAS Energy) (CET) Danske Gasteknik Center A/S (DGC) Electrochaea GmbH (EC) Electrochaea.dk ApS (EC.dk) Energinet.dk Nel ASA Rybjerggaard Biogas
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Content

Selected key terminology

In addition to subtask-specific glossaries that are provided in some documents attached to this report, the project leadership decided to provide definitions for selected terms that are central to the major story line. The list of terms is not exhaustive.

Power-to-x, P2X: A process that stores renewable electrical energy with of a different energy carrier and thus creates an alternative renewable fuel, e.g. e-methane, e-methanol, e-ammonia, hydrogen.

Power-to-methane: A biological or thermochemical methanation process using (green) hydrogen and CO_2 and transforming it into renewable methane.

Biological methanation/ Biomethanation: A biological process (e.g. as provided by Electrochaea's technology) that uses microbes to produce methane as the key output, i.e. biological methane/biomethane.

1 Introduction

a) Short description of project objective and results

English

The objective of this project is to prepare for building the first commercial biomethanation plant in the world – combining a 10 MW_e electrolyzer and a methanation facility integrated into an existing biogas plant in Roslev, Northern Denmark. The biomethanation system (to be provided by Electrochaea GmbH) will be advanced from TRL-6 to TRL-8 through design, execution, and integration into the host facility.

Deliverables

- Site integration
- Preliminary front end engineering design and preliminary engineering package to serve as a brief for the future EPC
- Assessment of (socio-economic) market potential for the biomethanation technology
- Analysis of ancillary grid services
- Investigation of regulatory framework conditions for biomethanation and suggestions for changes to embed the technology into the Danish energy system
- Detailed model of the plant, value stream strategy, and simulated operation
- Updated business plan

While the project was initially planned to last 12 months, delays led to a final project end on 30 April 2020 (as confirmed and approved by EUDP).

Dansk

Målet med dette projekt er at lave forberedelser til at bygge det første kommercielle biometanationsanlæg i verden. Anlægget skal kombinere en 10 MWe elektrolysanlæg og et methanationsanlæg integreret i et eksisterende biogasanlæg i Roslev, Norddanmark. Biometaniseringanlæg (leveres af Electrochaea GmbH) vil blive avanceret fra TRL-6 til TRL-8 gennem design, udførelse og integration i biogasanlægget.

Projektet har undersøgt følgende:

- Integration til existerende biogas anlægget
- Foreløbig frontend engineering design og foreløbig engineering pakke til at fungere som en fundament for den fremtidige EPC arbejde
- Vurdering af socioøkonomisk markedspotentiale for biometaneringsteknologien
- Analyse af systemydelser til elnettet
- Undersøgelse af lovgivningsmæssige rammebetingelser for biometanisering og forslag til ændringer for at integrere teknologien i det danske energisystem
- Detaljeret model for anlægget, værdistrømstrategi og simuleret drift
- Opdateret business plan

Mens projektet oprindeligt var planlagt til at vare i 12 måneder, sluttede projekten den 30. april 2020 (som bekræftet og godkendt af EUDP).

b) Executive summary

In September 25th, 2018, ten partners formed a consortium for the Danish Biocat Roslev Project 1 with the goal to provide crucial preparatory work for the first commercial scale biomethanation system worldwide. The partners jointly addressed two large and unresolved challenges of energy transition, i.e.

- utility-scale energy storage
- e-fuel production

Sector coupling is a precondition for a highly efficient energy system in the future. While biogas plants are yet to find a way to cut down their CO_2 emissions, PV plants and wind farms require an economic perspective once they fall out of the subsidy scheme. Power-to-methane can provide such a solution by consuming renewable electricity and re-utilizing CO_2 to produce e-methane. For this reason, related solutions are high on the agenda of Danish policy makers. Power-to-methane ("POWER-TO-METHANE") holds the potential to deliver on all these challenges with a flexible storage medium that uses CO_2 as the resource.

The project successfully ended on 30 April 2020. The work focused on site development activities, discussions with regulators and a sustainability assessment. In 04/2020, site integration assessment, a pre feed-study, business plan, identification of necessary permits and interest of important partners were completed.

The insights gained and the preparations carried out in Biocat Roslev project 1 will serve as a crucial base for moving ahead with the installation of the system on the site of a modern anaerobic digester and biogas upgrading / grid injection facility at Rybjerggaard near Roslev.

The project leadership is currently exploring how the project can be realized. Assessing potential funding possibilities and continued discussions with potential partners, suppliers and customers remain the tasks with the highest priority. Once those items are solved, the future system is planned to include an 10 MW_{el} electrolyzer linked to a biomethanation system with a capacity of up to 500 Nm^3/h CO_2 conversion. Furthermore, the plant will serve as a commercial-scale show case for a market-wide roll out across Denmark and the EU.

c) Structure of this report

1. The project was divided into three different work packages, WP2, WP3, and WP6. Each of those were again divided into subtasks. For a more detailed explanation of the objectives of each work package and their subtasks, please refer to subsection *Implementation* on page 8. The results of each subtask are described in the chapters 2-12.
2. The numbering of the work packages and subtasks originated from the original application which included not only all pre-development tasks, but also the erecting and integration of the plant into the biogas and farm operation on-site.
3. Subtasks 2.1, 3.1 and 3.2. cover all engineering-related subtasks that are required as part of the pre-development work. The results of these subtasks are documented in several technical files that are part of the appendix to this report and which are partly subject to confidentiality. Chapter 2 provides an overview of all activities and documents produced for the three subtasks mentioned.
4. At the time of project approval by EUDP, WP 2 was still divided into eight subtasks. As later requested by the project team and approved by EUDP, all regulatory-related project activities were consolidated under subtask 2.6. As a result, the scope of 2.5 was reduced to the assessment of the technical potential for biogas (author: Aalborg University). The content of 2.7 was fully integrated into 2.6.

5. The content structure of each chapter is closely aligned with EUDP's questions addressing the project results, if the questions were applicable to the tasks carried out within the subtasks.

d) Objectives, implementation, and evolvement of the project

In 2018, the project consortium around Biocat Roslev ApS received the discussed EUDP grant to start pre-development work on the Biocat Roslev project (Biocat Roslev Project 1). By providing the required funding, the EUDP supported the aim to undertake essential pre-development activities as a preparation for the planned follow up project 2 which will include the installation, integration, and optimization of the Power-to-methane plant.

Objectives

Throughout the project, the objectives and milestones were further refined and – where required – adapted in accordance with EUDP:

- Preliminary engineering package including a preliminary front-end engineering design to provide quantitative specifications for the financial model and to serve as a brief for the developer/ future EPC etc.
    - Site integration assessment
    - Heat management
    - Identification of duty cycles and operating modes
    - Basic block diagram
    - Basic layout
    - Battery limits
    - Scope of work & split of responsibilities
    - High-level process flow diagram
    - Systems specification sheet
- Analysis of electricity markets and ancillary services
- Analysis of power conversion for electrolyzers
- Pathway for permitting and environmental impact assessment
- Evaluation of the regulatory environment in the Danish gas and electricity markets to create an environment that makes an economic operation of Power-to-methane plants possible
- Operational modelling of the plant to understand sizing and value streams
- Analysis of GO scheme for methanised biogas: review of existing schemes, regulatory issues, and a conceptual model
- Market analysis, market modelling and market strategy in a socio-economic background for Danish power-to-methane installations
- Updated financial model based on the results from all other activities

Implementation

In accordance with the project outline that was developed for the application back in 2018, the specific objectives of the project were structured in work packages and subtasks. The final version of the overall implementation of the objectives is shown in the table below and the GANTT chart.

Work package structure based on latest change request

WP	Title	Results	Date of Change	Leadership	Reference
2.1	Site integration assessment and environmental impact screening	Define pathway for regulatory and environmental approvals and permitting	–	EC	Ch. 2 Appx. 01-Appx. 13
2.2	Investigate ancillary services status for grid stability and supply security	Electrical grid balancing strategy (scheduling and dispatch)	–	CET	Ch. 3 Appx. 32
2.3	*Original title* Preliminary environmental impact assessment *New title* Permitting	*Original result* Results of preliminary environmental impact assessment. *New result* Define which permits are needed for the plant	Feb. 2019 change request	BCR	Ch. 4 Appx. 33
2.4	State-of-the-art study for next generation power conversion for electrolysers	Benchmark for next generation power conversion for electrolysers	–	AAU-Tech	Ch. 5 Appx. 34
2.5	*Original title* Denmark POWER-TO-METHANE market regulatory framework outline, including regulatory, tax and tariff rules impacting pricing *New title* Technical potential for biogas upgrading	*Original result* Issue assessment of regulatory framework / assessment of the technical potential of biogas in Denmark *New result* Assessment of the technical potential of biogas in Denmark	Feb. 2019 change request	Initially DGC, changed to AAU-Dev	Ch. 6 Appx. 35

Work package structure based on latest change request					
WP	**Title**	**Results**	**Date of Change**	**Leadership**	**Reference**
2.6	*Original title* Find pathway through the regulatory boundaries or find sandbox agreement with authorities *New title* Danish POWER-TO-METHANE regulatory framework options, constraints, and suggestions for change	*Original result* Agreements with energy suppliers and off takers, or 'relief' agreements with regulators for sandbox *New result* Provide an overview of the situation for POWER-TO-METHANE in Denmark, i.e. current regulations, and constraints.	Feb. 2019 change request	DGC	Ch. 7 Appx. 36
2.7	Monitoring the requirements for policy changes	Proposal of necessary regulatory framework conditions/changes for POWER-TO-METHANE profitability	Integrated into 2.6	DGC	–
2.8	Update business plan	Update business plan with results of previous work packages including all relevant assumptions showing profitability level	–	BCR	Ch. 8 Appx. 37
3.1	Investigate site integration parameters and define battery limits for system design and responsibility scope	Site integration parameters and basic battery limits are drafted and the scope of work of all parties is defined	–	EC	Ch. 2 Appx. 14- Appx. 16
3.2	Investigate the heat integration system	Basic PFD, detailed Battery Limits description, M&E balance description	–	EC	Ch. 2 Appx. 17- Appx. 31

Work package structure based on latest change request					
WP	**Title**	**Results**	**Date of Change**	**Leadership**	**Reference**
6.1	Analysis of different value streams related to the plant, identifications of bottlenecks	Quantification of trading value and develop power trading strategy for the plant	For simplicity reasons, the results of WP 6.1 and 6.2 are consolidated in one detailed report	CET	Ch. 9 Appx. 38
6.2	Trading strategy maximization, analyse the effect of different regulatory schemes on the economic value of a power to methane plant	Optimize trading strategy for multiple products from the plant			
6.3	Map and assess the best sites for Power-to-methane in Denmark	Quantify and map power-to-methane potential in Denmark	Apr. 2019 change request: Leadership changed (Centrica -> AAU)	AAU-Dev	Ch. 10 Appx. 39
6.4	GO scheme for renewable synthetic methane	Develop conceptual GO model for renewable synthetic methane in Denmark	–	Energinet	Ch. 11 Appx. 40
6.5	Analysis of the overall economic effect of the technology on the Danish energy system	Develop an in-depth view of how methanation is impacting the Danish energy system from a socio-economic perspective	Apr. 2019 change request: Scope changed (Denmark and Europe -> Denmark)	AAU-Dev	Ch. 12 Appx. 41

			BCR	ELEC	NEAS	DGC	2018				2019												2020			
						-->	03. Sep	01. Okt	01. Nov	03. Dez	02. Jan	01. Feb	01. Mrz	01. Apr	02. Mai	03. Jun	01. Jul	01. Aug	02. Sep	01. Okt	01. Nov	02. Dez	01. Jan	03. Feb	02. Mrz	01. Apr
							1	2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
WPs	**Activity**	**Calendar year month -->**					M9	M10	M11	M12	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M1	M2	M3	M4
							1,8908	1,6807	1,6807	1,6807	1,6807	1,6807	1,6807	1,6807	1,6807	1,6807	1,6807	1,6807	1,6807	0,8403	0,4202	0,4202	0,4202	0,4202	0,4202	0,4202
1	Agreements (not part of EUDP funding scope)		X				■																			
2	Regulatory framework definition					X	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
3	Preparational activities for FEED and PDF			X			■	■	■	■	■	■	■	■	■	■	■	■	■							
6	Market model & strategy				X		■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Results (Milestones & Deliverables)																										
M1.1	Collaboration Agreement signed						■																			
D2.1	Definition of pathways: regulatory and environmental approvals																■									
D2.2	Electrical grid balancing strategy assessment completed																	■								
D2.3	Define necessary permits; Prepare necessary applications																							■		
D2.4	Benchmark for next generation electrolyzers established															■										
D2.5	Assessment of technical potential of biogas in DK													■												
D2.6 + D2.7	Overview of regulations and constraints; Propose necessary reg. framework cond.																						■			
D2.8	Updated Business Model for the Plant																									■
D3.1 / M3.2	Preparational activities for FEED and PFD done																		■							
M6.1	Quantification of trading value and power trading strategy																			■						
M6.2	Optimize trading strategy for multiple products of the plant																			■						
D6.3	Quantification and mapping of P2G potential in Denmark																■									
D6.4	Develop conceptual GO model for renewable synthetic methane in Denmark															■										
M6.5	In-depth view: Impact of methanation on DK energy system																	■								

Milestone (M): Project achievement

Deliverable (D): Document issued to Stakeholders and Grant organization

Evolvement

The project was coordinated and managed by Biocat Roslev ApS – the SPV established for the development of the biological methanation plant. The subtask work was led by dedicated project partners who ensured the timely delivery and quality of all results. With the strong and the continuous involvement of all project participants, the project succeeded in delivering on all objectives and ended by 30 April 2020. Looking back, the project leadership is very content with the output produced and expresses deep gratitude to all parties involved. The project did not experience unexpected problems.

The project work was carried out in accordance with the subtask-specific requirements to fulfill the objectives appropriately. The project consortium undertook several site visits in varying team compositions. Furthermore, several internal meetings and workshops were carried out to develop, share and discuss project output. Project delegates also visited relevant external parties to discuss potential collaboration during the future development of the site, to retrieve project-critical information from stakeholders (e.g. grid operators, DEA, members of the Danish parliament) and to promote Power-to-methane and the project in particular to the wider industry. Due to the restrictions derived from the Corona pandemic, the final project meeting including an optional presentation of results to an external audience have been postponed indefinitely. Finally, project participants contributed to the quality of the subtask output not only by producing the agreed deliverables according to the work package plan, but also by reviewing and editing reports for each other. The project leadership intends to continue collaboration with all participants beyond the funded project period with the mutual aim to promote e-fuel production and sector coupling in Denmark.

2 Results of all engineering-related project activities (2.1, 3.1, 3.2)

Lead author: Gorm Teper, Electrochaea GmbH

a) Objectives

This chapter lists all documents prepared by Electrochaea as part of the feasibility study and front-engineering study for a power-to-methane plant to be built on the premise of an existing biogas plant.

The study in question is related to the EUDP-funded project BioCat Roslev (64018-0064), which includes a feasibility study for the construction and operation of a Power-to-methane plant integrated to the existing Biogas plant, Rybjerg Biogas.

The objective of the three subtasks was to design the technical part of the plant according to the site specific requirements and optimise the technical setup between the existing site, the electrolyser and the methanation system in order for it to provide secure, easy to handle and efficient operation. More specifically, the deliverables of the subtasks were:

- to identify what interfaces exist on the farm, what new elements would the project bring and how the integration model would look like
- to clarify scope of work for the subsequent project development
- to create a project-specific approval and permitting pathway
- to obtain valid pricing parameters
- to conduct all essential pre-development activities as a preparation for the planned project development (installation, integration, optimization)

Amongst other success criteria, it was key to ensure the new installation would not negatively impact the existing operations of the farm and biogas plant in particular. One of the biggest risks identified in this work package was that the biogas plant with the biological methanation in place would be dependent on the new heat source provided by the Power-to-methane processes. For this reason, the project team had to design a suitable backup solution in order to prevent the biogas plant from being affected from any operational failures of the new installation and integration.

As the provider of the key technology, Electrochaea took the lead in developing all relevant output. In addition, it was essential to consult with not only Nel as a potential provider of the electrolyser technology but also the site owner and selected external parties including Danish authorities in order to retrieve the required information for the final engineering package.

b) Project results and dissemination of results

Looking back. the engineering subtasks succeeded in realizing their objectives. The basic design package can now be used to inform technology partners, the EPC and other service providers for building and integrating the plant. From a pure engineering perspective, the project is now ready for engaging an EPC. One major unexpected finding was the excess heat that would allow the biogas plant to process more feedstock and thus run at a higher capacity.

Due to the nature of the subtasks, the results are structured and presented in single documents as described below. Some documents are hidden due to IP sensitive information.

c) Subtask 2.1

Roslev Plant Layout

Confidentiality: Consortium only

The Plant Layout is a drawing of the plant building and immediate vicinity detailing the main components, their spatial integration and gross footprints. It shows ATEX perimeters and access points.

Roslev Piping Interface Layout

Confidentiality: Consortium only

The Piping Interface Layout is a drawing of the plant and immediate vicinity, detailing boundary limits and interfaces with other existing plants and equipment owned or operated by a third party, such as the biogas plant or the grid injection facility. A list of interface points is shown on the drawing legend.

List of Integration Items

Confidentiality: Consortium only

The List of Integration Items aims to capture all the material and energy streams that are foreseen to be exchanged between the existing biogas plant and ROSLEV Power-to-methane plant and also include items such as infrastructure (roads, cabling, piping etc.), data and so forth.

Utility List

Confidentiality: Consortium only

The Utility List details utility streams such as cooling water, instrument air etc, and provides key sizing parameters which will assist the EPC in cost estimates.

Request for Clarifications

Confidentiality: Consortium only

The Request for Clarifications is a questionnaire filled with project information from stake holders, listing the required inputs and answers regarding site specifics, operating parameters, market conditions and purpose of the project necessary for Electrochaea to propose a preliminary process and scope definition.

List of Permits

Confidentiality: Authors only.

List of relevant permits needed for planning, construction and operation of the P2G plant.

List of Certificates

Confidentiality: Public.

List of relevant certificates needed from the plant.

List of Suppliers, Contractors and Authorities

Confidentiality: Authors only.

List of possible suppliers, contractors and service provided who may be possible interfaces in the project delivery stage.

List of Existing Drawings

Confidentiality: Consortium only.

This List of Existing Drawings lists all drawings received by Electrochaea to support the preliminary design and studies on site integration.

Site Geo-technical Assessment Report

Confidentiality: Consortium only.

The report documents existing information on geo-technical condition of the site and provides recommendation for further study as part of the detailed engineering phase.

Conceptual Design Report

Confidentiality: Authors only.

This document provides a high-level description of the power-to-methane plant to be erected beside the Biogas plant Rybjergaard Biogas. It lists the site constraints, high-level dimensioning figures for each process unit and general integration concept. Several operation scenarios are defined.

Project Requirements Questionnaire

Confidentiality: Consortium only.

List of questions for consortium partners to ensure that the project team have adequately managed risk and addressed all project interfaces.

Project Glossary & Nomenclature

Confidentiality: Public.

This document lists and provides definitions of technical terms commonly used in the field of Power-to-methane and/or biological methanation.

d) Subtask 3.1

Responsibility Scope Matrix

Confidentiality: Consortium only.

The Responsibility Scope Matrix shows the scope splits between the project stakeholders and creates basis for the liabilities to be defined in the respective contracts. The project scope split in the document depicts the minimum expected engagement levels of the stakeholders for both project execution and operation phases but the scope of supply in the document depicts which main equipment and components have to be supplied by the stakeholders other than EPC Contractor and/or their engagement level in the project procurement.

Block Diagram

Confidentiality: Public.

The Block Diagram is the simplified graphical representation of the mechanical-electrical energy systems both in existing Biogas plant and the Roslev Biocat POWER-TO-METHANE plant, with the help of this document, the function of the systems can be described.

Battery Limit List

Confidentiality: Consortium only.

The Battery Limit List provides the normal operating conditions (viz. temperature, pressure) in addition to the flowrates for the feed stocks, products, by-products and supporting utility streams (Instrument air, N_2, Cooling water etc.). It will be further updated by the EPC contractor to establish the plant piping interfaces.

e) Subtask 3.2

Process Description

Confidentiality: Authors only.

A basic description of the methanation process which allows an EPC to understand how the P2G plant works and what the key equipment is.

Process Flow Diagram

Confidentiality: Authors only.

A drawing showing the main process blocks and their interactions.

Mass & Energy Balance

Confidentiality: Authors only.

A table which calculates all input flows and output flows. This table details flow and pressure for each process stream.

Operating Points Definition

Confidentiality: Consortium only.

The Nominal Operating Points Definition provides the flow and other process design parameters that define the operating and performance envelopes for the corresponding duty cycles of the biological methanation reaction system.

Piping & Instrumentation Diagram (Methanation Unit)

Confidentiality: Authors only.

A detailed set of drawings which show all equipment, valves and instrumentation and their relationship in the plant. A detailed cost estimate and basis of design can be made from it.

Process Flow Diagram PFD (Heat Interface)

Confidentiality: Authors only.

A drawing showing the main process blocks and their interactions regarding the waste heat handling.

Power Consumers List

Confidentiality: Consortium only.

Preliminary Power Consumption List provides the items/machinery that will require electrical energy to operate. The power draws/absorbed energies are estimated based on the selected electrical-mechanical energy conversion efficiency.

IO List

Confidentiality: Authors only.

A preliminary list of electrical inputs and outputs. This gives an EPC the magnitude of electrical works required for the project.

Valve & Fittings List

Confidentiality: Authors only.

Instrumentation List

Confidentiality: Authors only.

A list of all the Instruments needed for the methanation plant to operate automatically and provide feedback to the operators.

Equipment List

Confidentiality: Authors only.

A list of all the key equipment which make up the methanation plant. This list Is effective to understand the process and doing a cost analysis.

Pipe and Tube Classes

Confidentiality: Consortium only.

Pipe and Tube Classes specifies the minimum requirements for piping materials selection for various piping services in the process unit. Pressure ratings classes for the carbon steel and stainless steel grade piping are provided for a range of sizes that are applicable inside the biomethanation plant.

Preliminary Equipment Specification

Confidentiality: Authors only.

Preliminary ATEX zoning (Methanation Unit)

Confidentiality: Consortium only.

The Preliminary ATEX Zone Classification outlines the requirements for handling flammable gaseous components such as H_2, CH_4, H_2S, NH_3 etc., as per the EU directives/regulations. The zones are classified based on the likelihood of having a flammable mixture of gases in a working environment.

Preliminary 10MW Line List

Confidentiality: Authors only.

f) Utilization of project results and conclusion

The plant will use Electrochaea's Biomethanation technology, which addresses three key energy challenges: energy storage, renewable fuel production and CO_2 capture and utilisation. It is Electrochaea's aim to make the commercial operation of the Biocat Roslev plant a reality. For this reason, the company will re-apply for funding in order to continue with the next phase of the project. Grants will be used to partly fund the design, construction, commissioning and operation of the plant.

Electrochaea expects to use the results obtained commercially. The successful development and integration of the biological methanation plant is expected to serve as a commercial show-case for Electrochaea's solution and thus initiate a wider market roll-out that will lead to an increase in turnover for the company. From a plant perspective, the successful development will generate value to its owners, reduce CO_2 emissions, and require engineering, commissioning and operational staff. The commercial demonstration of a 10 MW PtX plant in Denmark will contribute to the Danish ambitions for green transition in general and will integrate well into the Danish roadmap for the development of PtX.

The subtask results are the engineering blueprint to make the Biocat Roslev plant a reality. Furthermore, the results will be used in other projects by making use of the preparatory engineering work, knowhow gained on site integration requirements, integration with electrolysers, and optimising the heat strategy within the system. Last but not least, the conducted project work enables Electrochaea to continue reducing CAPEX and OPEX levels and thus making its technology commercially feasible.

No Ph.D.s have been part of the subtask work. Furthermore. Electrochaea identified two topics during the design process in the feasibility study, where patents could be filed. The topics relate to efficient heat utilisation. No details can be given at this time, however Electrochaea intends to pursue these patent opportunities.

3 Investigate ancillary services status for grid stability and supply security (2.2)

Author: Lotte Holmberg Rasmussen, Centrica Energy Trading (CET; former Neas Energy)

a) Objectives

One of the benefits that a Power-to-methane plant can offer to the energy system is ancillary services for the electricity grid. To offer an effective commercial strategy for engaging in ancillary markets, the existing and projected conditions of the electricity markets available to Biocat Roslev were assessed. With CET heading this subtask, an analysis was made for grid balancing services.

b) Project results and dissemination of results

The results of subtask 2.2 are provided in Appx. 32. Subtask 2.2 succeeded in realizing its objectives. The subtask and its implementation developed as foreseen and according to the milestones set in the application. Subtask 2.2 included the research for, analysis of, and writing a report of the results. No real risks where involved – other than the risk of not being able to obtain information as this is an extremely complicated field of research.

The subtask was based on a thorough analysis of the electricity markets including ancillary services. To offer an effective commercial strategy, the subtask report provides the background knowledge for assessment of the existing and projected conditions in the electricity markets. This leads to an effective operation strategy based on commercial optimization of the plant. No unexpected results were found in subtask 2.2.

Subtask 2.2 has been disseminated by presentations of the results at project meetings to the other project partners and by the report written as part of the subtask.

c) Utilization of project results and conclusion

As the aim of the subtask was to analyse, no turnover was generated based on the results. As long as the project results will be realised in a real world POWER-TO-METHANE project, then it is expected that by participating in the different electricity markets there will be an increase in turnover and profits both for the POWER-TO-METHANE plant and for the balance responsible party (BRP) handling the electricity. At the plant and at the BRP there need to be people employed to make this happen.

The subtask did not involve any Ph.D. students. Furthermore, no patents are expected from the results of this subtask. The results are the know-how of how to value the flexibility of a power-to-x plant with electricity consumption of an electrolyser in the different electricity markets. This knowledge will be utilized in other possible projects and thus could be a commercial opportunity. CET is planning on using the knowledge to get even more involved in handling power-to-X plants in all the different electricity markets – both in Denmark and abroad. CET expects the result to be part of a product, where guidance and BRP services are provided to potential and established power-to-X plants. In addition to this, the project could also be the point of reference for further development and demonstrations project as P2X is an area that is in the launching phase of development. This subtask is an important element in realising the flexibility from power-to-methane as it will be necessary to use the flexibility in all available electricity markets to commercialise power-to-methane and trigger sector coupling.

4 Permitting (2.3)

Author: Johannes Peschko, Biocat Roslev ApS

a) Objectives

The objective of this subtask is to define which permits are needed for the plant. The necessary permits will be prepared and applications will be submitted as long as the given budget frame permits. If there is remaining work to be done, this will be included in project 2.

b) Project results and dissemination of results

The results of subtask 2.3 are provided in Appx. 36.

Subtask 2.3 succeeded in realizing its objectives to understand the necessary permitting landscape. In coordination with Skive Kommune (and in line with the description of the subtask) it has been decided that permits will be prepared once it is clear that the project will be erected and thus taking the final technical setup into account. The subtask and its implementation developed as foreseen and according to the defined milestones. Results are summarized in in the final subtask report. There were no risks involved that the task could not be fulfilled.

In cooperation with Niras and Rybjerggaard Biogas, Biocat Roslev and Electrochaea developed an exhaustive list of all necessary permits.

Once the decision is taken that the plant will be erected, the remaining permitting work will be completed. It is currently assumed that this process requires between 6 and 9 months.

c) Utilization of project results and conclusion

The results of the conducted preliminary assessment are instrumental for project 2. They will be used to prepare the necessary permitting applications and essential for structuring the future exchange with relevant authorities. The identified timeline is helpful to schedule the permitting tasks into the overall project timeline. Furthermore, the results of this project can (mostly) be used in other potential projects in Denmark. Last but not least, to patents are expected from the results of this subtask.

5 State of the art study for next generation power conversion for electrolyzers (2.4)

Authors: Pooya Davari, Shih-Feng Chou, Department of Energy Technology, Aalborg University

a) Objectives

Subtask 2.4 is a study on the optimal power supply for electrolysers. Electrolysers require electricity at high current and low voltage DC whereas the electricity grid uses low current and medium to high voltage AC. For this reason, a power conversion system needed. The subtask's objective was to increase the efficiency of transformer rectifier systems. The subtask was led by Aalborg university based on their extensive research experience and knowledge from related industry applications. the department was assisted by Nel Hydrogen, who provided details on current power conversion equipment used in the field and who helped in particular to understand the load profile of electrolysers in order to optimize the design of power supply. The input was then compared with different topologies in order to provide a valid recommendation on the power supply for the electrolyser to be installed at Biocat Roslev.

b) Project results and dissemination of results

Subtask 2.4 realized its objectives according to the plan specified in the application. The project did not encounter any unforeseen/ serious challenges. Furthermore, no PhDs were involved in the project. Appx. 34 includes the full report on the subtask. Amongst other items, the report contains a literature study on converter topologies used within the space of electrochemical processing, modelling of power losses within transformer rectifier systems and a comparison of converter system candidates taking the most important elements such as efficiency, complexity, reliability and controllability into account. In addition to the final report, the results were presented at project internal workshops in May 2019 and February 2020.

c) Utilization of project results and conclusion

The university did not take out any patents from the subtask. For some topologies, the subtask leaders would like to do more research. However, electrolytic loads may not be the priority. Other academic institutions have access to the final report and presentations.

6 Technical potential for biogas upgrading (2.5)

Authors: Iva Ridjan Skov, Steffen Nielsen, Malte Skovgaard Nørholm, Johann Pálmason Vestergaard, Aalborg University, Department of Planning

a) Objectives

In WP 2.5, a team from the Department of Planning of Aalborg University (AAU) created an overview of existing biogas resources and biogas production in Denmark. The analysis included mapping of manure, straw and municipal waste across municipalities in the country. Furthermore, the team presented research and development of biogas upgrading and biogas methanation technologies at existing plants including the status of electrolysis technologies. The potential for renewable energy integration was analysed for 3 Danish scenarios: reference 2020 as well as 2035 and 2050.

b) Project results and dissemination of results

The subtask answered the project proposal task description by looking into state-of-the-art of components for biogas derivates, resource mapping as well as the renewable energy integration potential. The analysis led to the conclusion that biogas methanation will be one of the key technologies in future renewable energy systems. Subtask 2.5 fulfilled its objectives according to the plan specified in the application. The project did not encounter any unforeseen/ serious challenges. Furthermore, no PhDs were involved in the project. Appx. 35 includes the full report on the subtask. The subtask report is publicly available.

c) Utilization of project results and conclusion

The results can be used for future research in the area or as a base for the expansion of the work conducted for another project. As the potential for biogas resources can vary from year to year, these results can always be updated with newer numbers. The results for the potential for the integration of the renewable energy are basic results that indicate the potential of methanation technology and can be used for comparison with other PtG or PtL options. The results give insights into the potential for renewable electricity integration in the future energy system with targets to be 100% renewable energy based in 2050.

7 Denmark power-to-methane market regulatory framework outline, including regulatory, tax and tariff rules impacting pricing (2.6)

Authors: Thomas Hernø (Danish Gas Technology Centre a/s), Tejs Laustsen Jensen and Line Strauss Jørgensen (Hydrogen Denmark), Lotte Holmberg Rasmussen (Centrica Energy Trading A/S), Peter Plesner (MrCleantech.dk), Johannes Peschko and Sebastian Karban (Biocat Roslev ApS)

a) Objectives

The current Danish regulatory framework poses the challenge that it is not designed to include energy storage, CO_2 storage, e-fuel production and/or sector coupling technologies in particular in the electricity and gas sectors. Furthermore, it is not meant to accommodate e-methane produced from waste CO_2. Because of these existing conditions, a commercially feasible Power-to-methane project is not possible. In other words, the commercial roll-out of power-to-methane in Denmark will happen once the appropriate regulatory environment is in place.

The objective of subtask 2.6 was to assess the specific situation for power-to-methane in Denmark considering all key stakeholders in the process, current regulations, and constraints. There is an ongoing discussion on the requirements and possible solutions to promote the domestic production of e-fuels. Aims of this sub task were to clarify the current status of discourse and to make specific suggestions for legislation, regulators and energy authorities.

As discussions and policy development are still ongoing at the time or report finalisation, the team set 31 October 2020 as the editorial deadline. Having said that, the project team acknowledges Denmark's commitment as well as already achieved milestones to date, e.g. the formation of the climate partnerships[1] and the 21 June 2020 parliamentary decision to commit to 70 % reduction of greenhouse gas emissions from 1990 levels by 2030, to building energy islands, and to invest in carbon capture and green fuels[2].

b) Project results and dissemination of results

The results of the subtask are described in detail in Appx. 36 and sub-divided into Part 1 (summary of all analytical work) and Part 2 (regulatory pathway).

The subtask realised its objectives - to the extent that the team…

1. …produced an overview of the situation for power-to-methane in Denmark and looked at current regulations and constraints (part 1)
2. …created a set of recommendations to advise for Danish policy makers in their efforts to embed power-to-methane into the regulatory system (part 1 & 2)
3. …approached policy makers, regulatory bodies, energy agencies, public and private stakeholders in order to create transparency on the potential of power-to-methane for the Danish energy system and to explore potential regulatory solutions for Biocat Roslev (dissemination, part 2)

[1] https://investindk.com/insights/danish-climate-partnerships-lead-the-way-for-a-global-sustainable-future#:~:text=The%20climate%20partnerships'%20final%20contributions,gases%20in%20Denmark%20by%202030.

[2] https://www.bloomberg.com/news/articles/2020-06-22/danish-parliament-strikes-historic-climate-deal-to-cut-emissions

c) Utilization of project results

No patents were taken out from the results of this subtask and no Ph.D. student was part of carrying out the subtask. As described in the results section, the analytical work of this subtask is the groundwork to develop regulatory recommendations for the Danish authorities. Furthermore, the quantitative parameters were used to refine the financial model and the wider business plan (subtask 2.8). From a project development perspective, the results form a set of key actions to be taken for the project going forward.

Beyond project-specific takeaways, the results of this subtask are key to understand the Danish regulatory system for the power-to-methane market. Therefore, the results can be used for other similar project opportunities in the power-to-methane field. Assuming that the current regulatory environment will be modified in order to accommodate the production of e-methane, the reutilization of CO_2 and the storage of electricity, the market conditions in Denmark carry significant potential for a wider roll-out.

8 Update business plan (2.8)

Author: Johannes Peschko, Biocat Roslev ApS

a) Objectives

One of the project's objectives was to assess whether it makes sense to realize the planned project. The basis for this decision is an economic model originating from the preparation of the EUDP project application back in 2018.

The objective of subtask 2.8 is to update the business plan with the results of other subtasks/ work packages including all relevant assumptions that have an effect on profitability levels.

b) Project results and dissemination of results

The results of subtask 2.8 are provided in Appx. 37.

Subtask 2.8 succeeded in realizing its objectives. The subtask and its implementation developed as foreseen and according to milestones. There were no risks involved that the task could not be fulfilled.

The report concludes that a business case generating positive returns is feasible under realistic assumptions, showing 5.2 % IRR for the *Base Case* and 22 % IRR for the *Better Case.* However, all scenarios are either based on finding agreements with market participants which are not governed by the current regulatory system or on adaptions of the regulatory framework to integrate Power-to-methane installations. For example, the large increase in profitability that can be generated by including the 24 MW of wind turbines in a behind-the-meter solution, needs the approval to re-power the existing wind turbines and the possibility to use the generated electricity as "behind the meter" electricity. TSO and DSO tariffs that need to be paid for electricity consumption by electrolyzers are making the difference between the -13 % IRR of the *Worse Case* to the 5.2 % IRR of the *Base Case*. Therefore, the positive effect of the "behind the meter" solution would also be possible to achieve with an exemption of TSO and DSO tariffs for the electrolyzer.

The second large influence factor is the pricing for the e-methane produced. Under the current regulatory system, this renewable and completely carbon-neutral gas would only receive the exceptionally low market price for fossil natural gas. A project will only be possible if a private buyer agrees on paying a premium for this premium product in a private contract or if e-methane would be included in the regulatory system. Overall, the report concludes that building such a plant yields positive returns, granted the assumptions used. Subtask 2.8 has been disseminated by presentations of the results at project meetings to the other project partners and by the report written as part of the subtask.

c) Utilization of project results

The results of this subtask are instrumental for any follow-on project. They will be used in negotiations and discussions taking place over the coming months to refine the economic feasibility of the plant and for the planning of a project realisation. Furthermore, the model has generated a deep understanding of the economic integration of PtX plants at biogas plants and beyond. It has been constructed in a very flexible way so that it can (and will) be used as master for other sites and project opportunities. No patents are expected from the results of this subtask.

9 Analysis of different value streams related to the plant, identifications of bottlenecks, and optimization of trading strategy (6.1, 6.2)

Authors: Lotte Holmberg Rasmussen, Bruno Bez, Centrica Energy Trading ("CET"; former Neas Energy)

a) Objectives

Subtasks 6.1 and 6.2 focus on the analysis of the various value streams and on ways to optimize the corresponding trading strategies to maximize profitability of the overall biological methanation plant. Core value streams are renewable electricity as the main input factor, e-methane as the primary product and heat. Accordingly, the demand for methane (and hence hydrogen), heat as well as the price fluctuations on renewable electricity and gas and the availability of renewable power must be considered. The trading strategies directly depend on sizing and technical behavior of the plant.

The subtasks evolved as planned, but adjustments had to be made as 6.2 was originally supposed to be written only once the plant was in operation. Instead, the team used EnergyPRO to model and simulate the operation and perform the required analyses.

The analyses use assumptions that involve future prices and markets. Future prices are intrinsically uncertain and may develop very differently from historic prices. To minimize the risk, sensitivity analyses have been carried out regarding the uncertainties. The largest challenges were to set up the EnergyPRO modelling and get it to work carefully considering more than one electricity market. Furthermore, it was critical to define the assumptions that were used in the model.

b) Project results and dissemination of results

The objectives of both subtasks were fulfilled and are shown in detail in Appx. 38. No unexpected results were found. Both the working progress and the results were disseminated via presentations at project meetings and by the report written as part of the subtask.

As the aim of the BioCat Roslev project is to analyse, no turnover has increased following subtask 6.1 and 6.2. If the project results in the Power-to-methane project being realised, then it is expected that by participating in the different electricity markets modelled in 6.2 there will be an increase in turnover and profits both for the POWER-TO-METHANE plant and for the balance responsible party (BRP) handling the electricity. At the plant and at the BRP there need to be people employed to make this happen. The results from subtask 6.1 and 6.2 will be used for optimizing the operation of the plant and thus the business case.

c) Utilization of project results

The results are the know-how of how to analyse and operate the flexibility of a power-to-x plant with electricity consumption of an electrolyser. This knowledge can also be utilized in other possible projects and thus represent a commercial opportunity. CET is planning on using the knowledge to get even more involved in handling and optimizing the operation of power-to-X plants in all the different electricity markets – both in Denmark and abroad. CET expects the result to be part of a product where guidance and BRP services are provided to potential and established power-to-X plants. In addition to this, the project could also be the point of reference for further development and demonstrations project as P2X is an area of early-stage development.

The subtasks are important elements in understanding the main value streams of a power-to-methane plant and building a suitable optimized operation mode, helping to maximize the operational profit. No patents are expected. No PhDs have been part of the project.

10 Map and assess the best sites for Power-to-methane in Denmark (6.3)

Authors: Steffen Nielsen, Diana Moreno, Iva Ridjan Skov, Aalborg University, Department of Planning (AAU-Dev)

a) Objectives

In subtask 6.3, a team of AAU-Dev estimated the potential for biogas methanation plants based on a spatial analysis of the existing biogas producers. The analysis evaluated distances to electricity and gas infrastructure, as well as local wind potentials. Furthermore, each location was evaluated in terms of existing gas injection, distance to district heating and to CNG stations.

b) Project results and dissemination of results

As part of the subtask an interactive online map model was developed where users can identify potential locations themselves based on the capacities of the biogas plants or electrolysis unit they are interested in. We do believe that the subtask has sufficiently answered the problem stated in the project proposal.

The results show that the total theoretical production potential of e-methane from biogas is around 6,666 GWh/year. From this potential around half of the locations are suitable for biogas methanation. The report also shows that this conclusion is highly sensitive to the criteria used, if longer distances to gas and electricity networks is allowed, then the share increases.

The results of the subtask have been disseminated at the Smart Energy System conference in Copenhagen held September 10-11, 2019.

Subtask 2.5 fulfilled its objectives according to the plan specified in the application. The project did not encounter any unforeseen/ serious challenges. Furthermore, no PhDs were involved in the project. Appx. 39 Includes the full report on the subtask. The subtask report is publicly available.

c) Utilization of project results and conclusion

The results can be used for future research in the area. As the tool created can be further developed, the team expects it will use it as a platform for expanding on this research area. The results can point out potential locations for power-to-methane locations in Denmark that is part of the policy objectives for further funding in the area.

11 GO scheme for renewable synthetic methane (6.4)

Author: Jeppe Bjerg, Energinet.dk

a) Objectives

Subtask 6.4 had the purpose to develop a conceptual model for issuing guarantees of origin (GO) for renewable synthetic methane (e-methane). Such scheme would have to be in line with the existing Danish biomethane GO scheme, EU regulation and other European GO schemes. Once created and implemented, the GO scheme is meant to serve as a transparent and trustworthy documentation scheme providing the required certification for producing, trading and consuming e-methane. From Energinet's perspective, it is key for Denmark to take a leading role in implementing EU law in national regulations and thus maintaining the claimed leadership position for the Danish energy sector and its participants.

To implement this GO process and certification scheme as a follow-up to this subtask, the following tasks were performed:

- Generate an overview of GO schemes for renewable hydrogen and subsequently synthetic methane in EU/worldwide.
- Describe requirements for the hydrogen/biomass to be defined as renewable.
- Complete an assessment of other bilateral/multilateral GO schemes such as AIB (renewable electricity), CertifHy (green and renewable hydrogen), The European Renewable Gas Registry (cross- border trade of biomethane GO) or bilateral agreement enabling cross-border transfers of GO between two countries, in order to ensure coherence where possible.
- Complete an assessment of current and projected EU regulations which may influence the issuing and utilization of GOs.
- Formulate a conceptual model of the GO scheme for roll out in Denmark

b) Project results and dissemination of results

The subtask did not encounter any unforeseen/ serious challenges. Furthermore, no PhDs were involved in the project. Appx. 40 includes the full report on the subtask. The subtask report is made public via the Biocat Roslev project report.

c) Utilization of project results

The results of this subtask are and will be used for the development of the GO scheme. While Energinet expects some additional revenues from the application of the future scheme, the relevant business growth is to be expected across the economy from the production and consumption of e-methane. Energinet.dk expects that the implementation and application of the GO scheme will incite the development of e-methane plants, lead to a substantial increase of gas green gas production and create value from excess renewable power. No patents were taken out of the subtask. A spinoff in terms of a concept for granular guarantees of origin is being developed further outside of this project.

12 Analysis of the overall economic effect of the technology on the Danish energy system (6.5)

Authors: Iva Ridjan Skov, Andrei David, Brian Vad Mathiesen, Aalborg University, Department of Planning (AAU-Dev)

a) Objectives

In subtask 6.5, a team of AAU-Dev evaluated the techno-and socio-economic potential of biogas upgrading in Denmark. This work package built on the relevant findings from WP2, and also considered the economics of electro-fuel production.

Additional data collection was an essential part of this subtask. Project partners provided input on the technical and economic characteristics of their technologies, either from demonstration plants or related knowledge (i.e. other projects). The analysis of this data regarding the potential role and use of biogas in the future energy system in Denmark will be performed with the energy system analysis tool developed by AAU (www.energyPLAN.eu). EnergyPLAN is a deterministic energy model used extensively in the modelling of 100 % renewable energy systems and developed on the concept of a Smart Energy Systems. The analysis includes an assessment on the placement of biogas plants across Denmark in relation to but not only the end use, the gas, electricity, and district heating grids but also to current or future energy systems.

The analysis focused on the potential socio-economic market value and investment level for deployment of these technologies in future energy systems. The report did evaluate project-specific business cases and economic challenges.

The main risks in this project were identified as the following:

- The regulatory framework does not allow for economic operation
- Innovative technologies cannot be designed as planned in the proposal
- Poor communication between stakeholders
- Unforeseen delays to planned timeline and completion
- Unforeseen extra costs

The project experienced unforeseen delays to the planned timeline and struggles for the regulatory framework to allow for economic operation of the integrated plant. Other than that the subtask evolved as planned. No risk was associated, and no problems encountered.

b) Project results and dissemination of results

The subtask succeeded in realizing its objectives and answered the problem stated in the project proposal. The analysis included eight scenarios that simulated the utilization of biogas, biomethane or e-methane for power production, industrial purposes or transportation. Results show both fuel costs, system costs and biomass consumption. Furthermore the analysis included the growth curves and needed investment levels to reach the projected capacities of electrolysis and e-methane in the energy system for both Denmark and EU. The subtask team concluded biogas methanation to become one of the key technologies in future renewable energy systems.

The results of the subtask have been disseminated at the Smart Energy System conference in Copenhagen held September 10-11, 2019.

c) Utilization of project results

The subtask offers a comparison of different utilizations of biogas and its derivatives and how these contribute to the energy system transformation in the targeted 100% renewable energy system.

No patents were taken out of the subtask. The subtask results are not used for teaching but are a part of the research article that was generated as a part of a PhD project[3]. The results will be used as a basis for further research in the area, for example, a comparison with other types of PtG options in the energy system that could be generated in the research group as part of other projects.

[3] "The role of biogas and biogas-derived fuels in a 100% renewable energy system in Denmark": https://www.sciencedirect.com/science/article/pii/S0360544220305338

13 Conclusion: Dissemination and utilization of project results, outlook, and next steps

From a Biocat Roslev perspective, the results of project 1 will serve as a basis for future negotiations with investors, operators, service providers, electricity traders and gas consumers to make the realisation of the project happen. Furthermore, the output is and will be integrated in future funding applications. Last but not least, project participants are at liberty to make use of the learnings and apply them in other projects. Confidentiality is limited to the items that were specified for each subtask in the earlier chapters.

The project leadership in collaboration with the key technology provider Electrochaea is working on suitable ways for developing Biocat Roslev as planned. These efforts include targeted raising of private and/or public funding for the envisaged plant configuration. Having said that, key turning point for the continuation of the project is and will be the precise regulatory tools that will integrate green gases other than conventional biogas into the Danish energy system – including adequate rewards for CO_2 reutilization and for renewable electricity storage. The resulting economic parameters will determine the bankability of the planned Biocat Roslev project in particular but also the wider marketability of biological methanation across Denmark. The project leadership is confident that Danish policy makers will soon provide a suitable regulatory solution to the market for power-to-x to become a cornerstone of the Danish green transition.

14 List of Appendixes[4]

Appx. 01 Roslev Plant Layout

Appx. 02 Roslev Piping Interface Layout

Appx. 03 List of Integration Items

Appx. 04 Utility List

Appx. 05 Request for Clarifications

Appx. 06 List of Permits

Appx. 07 List of Certificates

Appx. 08 List of Suppliers, Contractors and Authorities

Appx. 09 List of Existing Drawings

Appx. 10 Site Geo-technical Assessment Report

Appx. 11 Conceptual Design Report

Appx. 12 Project Requirements Questionnaire

Appx. 13 Project Glossary & Nomenclature

Appx. 14 Responsibility Scope Matrix

Appx. 15 Block Diagram

Appx. 16 Battery Limit List

Appx. 17 Process Description

Appx. 18 Process Flow Diagram

Appx. 19 Mass & Energy Balance

Appx. 20 Operating Points Definition

Appx. 21 Piping & Instrumentation Diagram (Methanation Unit)

Appx. 22 Process Flow Diagram PFD (Heat Interface)

Appx. 23 Power Consumers List

Appx. 24 IO List

Appx. 25 Valve & Fittings List

Appx. 26 Instrumentation List

Appx. 27 Equipment List

Appx. 28 Pipe and Tube Classes

Appx. 29 Preliminary Equipment Specification

Appx. 30 Preliminary ATEX zoning (Methanation Unit)

Appx. 31 Preliminary 10MW Line List

[4] This list includes all appendixes for both the public version of the report and the version for the consortium only. Confidential documents are mentioned in the main body of the text but not in this list.

Appx. 32 WP2.2 "Electricity markets including ancillary services with focus on Denmark West"

Appx. 33 WP2.3 "Permitting"

Appx. 34 WP2.4 "State of the art study for next generation power conversion for electrolyzers"

Appx. 35 WP2.5 "Screening of biogas methanation in Denmark. Resources, technologies and renewable energy integration"

Appx. 36 WP2.6 "Danish P2G regulatory framework"

Appx. 37 WP2.8 "Updated Business Case"

Appx. 38 WP6.1 and 6.2 "Value streams and operation modelling"

Appx. 39 WP6.3 "Mapping of biogas methanation potential in Denmark. Based on existing biogas sources"

Appx. 40 WP6.4 "A GO Scheme for methane. Existing schemes, regulation and a conceptual GO model"

Appx. 41 WP6.5 Report "Biogas utilisation in the energy system and market potential for biogas methanation"