Final report

1.1 Project details

Project title	Demonstration of Novel Biogas Upgrading Technology / Demonstration af ny teknologi til biogas opgradering
Project identification (program abbrev. and file)	EUDP 64013-0532
Name of the programme which has funded the project	Energiteknologisk Udviklings- og Demonstrationsprogram (EUDP)
Project managing company/institution (name and address)	HMN Biogas Aps, Gladsaxe Ringvej 11, 2860 Søborg. The project was transferred from HMN Gashandel A/S 1st January 2016 due to reorganization of HMN.
Project partners	Akermin Inc. Ammongas A/S BIOFOS Avedøre Spildevandscenter A/S Dansk Gasteknisk Center A/S Novozymes A/S
CVR (central business register)	HMN Biogas Aps: 3727 0075 HMN Gashandel A/S: 27061885
Date for submission	16th December 2016

1.2 Short description of project objective and results

English version:

The project objectives, when the project was initiated, were:

The project will demonstrate an innovative environmental-friendly technology for biogas upgrading. The technology uses enzyme-based biocatalysts to accelerate the CO_2 absorption. The consumption of electrical power and steam is thereby reduced resulting in expected cost savings of 25%.

The project was closed down prematurely without demonstrating upgrading of biogas using the enzyme based upgrading technology or generating results on potential energy and cost saving due to the premature closing. However, the project demonstrated the ability of the enzyme based biocatalyst to enhance CO_2 absorption, methods for manufacturing of the biocatalyst were developed and the technology for biocatalyst upgrading was partly developed.

Danish version:

Projektets formål var, da projektet blev sat i gang:

Projektet vil demonstrere en ny banebrydende miljøvenlig biogas-opgraderingsteknologi. Teknologien benytter enzym baserede bio-katalysatorer som accelererer CO_2 absorptionen. Forbruget af el og damp reduceres herved, hvilket resulterer i forventede omkostningsbesparelser på 25%.

Projektet har ikke, på grund af at projektet blev stoppet tidligere end planlagt, demonstreret teknologien eller mulige energibesparelser og omkostningsreduktioner. Imidlertid blev det demonstreret, at den enzymbaserede biokatalysator kan forstærke CO_2 absorbation, der blev udviklet metoder til fabrikation af biokatalysatoren og teknologien til biokatalysator baseret opgradering blev delvis udviklet.

1.3 Executive summary

Unfortunately, the Demonstration of Novel Biogas Upgrading Technology project (short name "ENZUP") was closed down prematurely without demonstrating upgrading of biogas using the enzyme based upgrading technology.

Since 2014, HMN has cooperated with the project partners BIOFOS Spildevandscenter Avedøre A/S, Akermin Inc., Ammongas A/S, Novozymes A/S, and Dansk Gasteknisk Center on designing and implementing a demonstration biogas upgrading plant at BIOFOS' Avedøre waste water treatment plant (WWTP).

The plant was intended to demonstrate a more cost effective method for upgrading biogas from the waste water treatment process and inject it in the natural gas grid as green natural gas. The ENZUP upgrading technology used enzymes in a biocatalyst to minimize the energy consumption in the upgrading process.

The closing of the ENZUP project is primarily caused by the closing of the US-based partner Akermin summer 2016. Akermin developed the enzyme based upgrading technology and was intended to deliver the enzyme based biocatalyst for the daily operation within the ENZUP project and for future commercial operation. Without the biocatalyst supply, the basis does not exist for the ENZUP plant and future plants using the same technology. Akermin had for an extended period been challenged by intellectual property issues and the right to implement the enzyme based upgrading technology. This affected Akermin's financial situation and the ability to attract investors negatively, and finally led to the closing of the company.

In the project the ability of the enzyme based biocatalyst to enhance CO_2 absorption was demonstrated in a large scale pilot plant in Akermin's laboratory, methods for manufacturing of the biocatalyst were developed and the technology for biocatalyst upgrading was partly developed. Furthermore, Novozymes developed the enzyme for the biocatalyst further.

The upgrading plant was in process of being implemented on the WWTP, when the project was closed down. Most of the system integration with the WWTP and the neighbor methanation project (Electrochaea's ElForsk funded BioCat II project) systems were completed, as well as the building and foundations for the ENZUP upgrading plant.

As the upgrading plant would replace the WWTP's gas engine as the main biogas consumer, the internal heating system on BIOFOS was altered to reduce heat consumption and utilize waste heat from other sources than the engines cooling system.

HMN will replace the ENZUP plant with a conventional upgrading plant with the same capacity on BIOFOS' WWTP. Ammongas will be in charge of adapting the ENZUP plant to a commercial technology amine plant. The HMN upgrading plant will upgrade biogas and inject it in the natural gas grid just like the ENZUP plant, but with a less innovative technology. The plant is expected to be operational spring 2017.

In the marketing of green natural gas, the upgrading facility is still a relevant and interesting project, integrating biogas upgrading and methanation with biogas production from waste water treatment, located close to a big city, and injection of bio methane in the natural gas grid.

1.4 Project objectives

The project objectives were:

The project will demonstrate an innovative environmental-friendly technology for biogas upgrading. The technology uses enzyme-based biocatalysts to accelerate the CO_2 absorption. The consumption of electrical power and steam is thereby reduced resulting in expected cost savings of 25 %.

This involved several development areas:

- Enzyme development and biocatalyst development and Up-Scaling
- Biocatalyst upgrading process
- System integration of upgrading plant and WWTP
- WWTP Heating system alterations

Enzyme development and biocatalyst development and Up-Scaling (Novozymes and Akermin)

The prototype enzyme for CO_2 capture was already developed when the project was initiated. Novozymes matured the enzyme production process further during the project to prepare for scale-up and meet technical requirements of the integrated biocatalyst system. This activity developed as foreseen. Akermin and Novozymes developed the biocatalyst for the production process. The biocatalyst development activity changed character during the project due to the upgrading technology changes described in section 1.5, but developed as foreseen.

Biocatalyst upgrading process (Akermin and Ammongas)

Akermin developed the biocatalyst upgrading process with the engineering assistance from Ammongas. During the project several challenges were identified and managed through changes in the upgrading process concept as described in section 1.5. The major challenges were the biocatalyst ability to operate in the harsh environment in the upgrading plant and the biocatalyst's behaviour in the process liquid.

Even though the upgrading technology initially seemed to be the major challenge, an Intellectual Property (IP) issue turned out to initiate the premature closing of the project

Akermin entered the ENZUP project in 2013 having a strong IP position for its unique biocatalyst driven approach for removing CO_2 from industrial gas streams, including upgrading biogas. A key competitor was CO2 Solutions, Inc. (CSI), a Québec-based public company also developing an enzyme-based approach for CO_2 removal. Even though CSI's patent portfolio revealed some issued patents in Canada and the US, due to a significant amount of prior art Akermin felt confident of freedom to operate in Europe and specifically in Denmark for demonstrating the novel biogas upgrading technology.

In November 2014 CSI filed Danish Utility Model patent applications. A Danish Utility Model (UM, in Danish Brugsmodel) patent is a special case situation intended to provide protection to local small operators with limited resources for initial proof of concept inventions. The UM provides 10 years of patent protection versus 20 years for a standard patent.

It is intended for System only patents, not for process or methods claims and most importantly, has a lower somewhat ambiguous standard or threshold of proof for patent issuance. This UM is based on a CSI patent application in the European Patent Office (EPO). Both Novozymes and Akermin felt this UM application was flawed and thus submitted objections through the only available methods of communication with the Danish patent office; 3rd party observation letters. In Summer 2015

the efforts prevailed when a rejection notice for the UM was issued by the patent office.

However, before the decision to reject the UM was finalized a new examiner took over the case. Following a conference call directly with CSI (neither Novozymes nor Akermin were privy to those conversations) Akermin was apprised in December 2015 that the new examiner reversed the decision of the previous examiner and allowed the UM patent. The examiner also noted that the office would not accept any additional 3rd party arguments and any further objections would have to be filed in an administrative re-examination after the issuance of the UM patent.

At this point Akermin retained additional Danish counsel whose review suggested a further position for rejection of the UM. These objections were based on novelty and insufficient creative disclosures. Thus once the UM was registered and issued on January 2016 Akermin filed for an administrative re-examination. A re-exam typically takes 4-6 months to conclusion. Based on all available evidence including the new discoveries by the European council Akermin strongly believed that the re-examination would be successfully overturning the UM. End of June 2016 the Danish patent office confirmed CSI's UM.

Recognizing that there were no guarantees for a successful overturn, Akermin initiated license discussions with CSI before the confirmation of the UM. The negotiations led to a draft licence agreement. The ENZUP partners wanted the UM re-examination to be finalised before signing the agreement. At this stage the financial situation of Akermin had developed negatively and Akermin chose to close down the company in a process similar to a standard US bankruptcy proceeding.

As a possible mitigation strategy Akermin performed an economic and technical analysis of the option of converting the current unit into one capable to accommodate the CSI's enzymatic approach. Akermin could not recommend this, as it would not be economical from either CAPEX or OPEX perspectives. A major modification of the already purchased equipment would be required. Moreover, the competitor-based approach is significantly more energy demanding and would not fulfil the project objective of demonstrating more cost effective biogas upgrading.

System integration of upgrading plant and WWTP (HMN and BIOFOS)

System integration of the upgrading plant in the biogas system of BIOFOS' WWTP proved more complicated and costly than expected, but developed as foreseen resulting in a full integration of biogas production, existing biogas flare and gas engine (for backup), the neighbour methanation plant and the facilities for bio methane injection in the natural gas grid.

WWTP Heating system (BIOFOS)

BIOFOS' alteration of the internal heating system was initially planned in two phases. During the engineering phase the two phases were integrated. This activity developed as foreseen.

Measurement programme

Dansk Gasteknisk Center A/S (DGC) had a minor role in the project being responsible for the measurement programme for documentation of the upgrading plant's performance. The programme was developed and measurement requirement were specified and delivered to Ammongas for engineering.

1.5 Project results and dissemination of results

Enzyme development and Biocatalyst Development and Up-Scaling (Novozymes and Akermin)

The novel biocatalyst developed for use in ENZUP is a unique integration of a well-performing prototype carbonic anhydrase enzyme developed by Novozymes together with a robust, porous polymeric enzyme entrapment matrix developed by Akermin. Carbonic anhydrase enzyme adds value in biogas upgrading by accelerating the rate at which CO_2 is separated from the raw biogas during the biogas upgrading process.

Specifically, carbonic anhydrase selectively catalyses the reaction of CO_2 with water to form biocarbonate anion, which is readily soluble in the absorption solution used for the separation process. Separation of CO_2 from the raw biogas produces a purified methane gas stream that can be further conditioned for injection into the gas grid. The separated CO_2 can be released, or, in conjunction with the co-located Bio-Cat project, could be converted to additional methane.

The biocatalyst matrix developed by Akermin is especially suitable for providing carbonic anhydrase to the biogas upgrading reactor with the necessary performance and stability features. Carbonic anhydrase molecules are sufficiently large to be entrapped by the biocatalyst's porous polymeric matrix, while remaining accessible to the low molecular weight CO_2 and water reactants. CO_2 and water pass through the pores of the matrix and are converted to bicarbonate at the enzyme's catalytic active site, resulting in selective transfer of CO_2 from the biogas stream to highly soluble bicarbonate ions in the absorption liquid. This "loaded" liquid is circulated to a desorber stage (stripper column), where CO_2 is released, and the "lean" liquid is recycled to the absorber.

Particulate biocatalyst is a solid material that can be retained in the absorber stage using solid-liquid separation techniques, enhancing biocatalyst efficiency and longevity. Therefore, the combination of the enzyme and polymeric entrapment technologies results in a solid particulate biocatalyst material that is well suited to perform optimally as a CO_2 absorption catalyst in the biogas upgrading unit. Desirable biocatalyst features include high mass transfer efficiency, ease of use due to biocatalysts particles can mix and travel along with the absorption liquid, ease of solid-liquid separation to fit with various process configurations, and ease of biocatalyst recycling and replenishment.

CO_2 removal is further enhanced by physical features designed into the biocatalyst particles that allow the particles to preferentially reside near the gas-liquid interface and enhance reaction mass transfer. Also, the entrapment matrix stabilizes the enzyme, allowing for extended biocatalyst longevity.

Prior to commencement of the ENZUP project, the polymeric entrapment technology was demonstrated as a fixed coating on the surfaces of packing inside a CO_2 absorption column, but this approach was limited by the difficulty in replenishing the biocatalyst coating. A particulate biocatalyst that can travel along with the process liquid does not have this drawback. Development of the particulate biocatalyst utilized for ENZUP included selection and inclusion of production steps that would be readily scalable to commercial requirements and broad deployment.

In support of the project, Novozymes adapted certain enzyme production steps and made adjustments to the soluble enzyme solution composition for compatibility and ease of incorporation with chemicals and process steps used by Akermin to generate the final solid biocatalyst particles. Similarly, Akermin made adjustments to the entrapment matrix and processes to achieve optimal results with the Novozymes enzyme.

The collaboration included lab scale pre-qualification testing of intermediate enzyme and biocatalyst products followed by lab scale performance verification testing and, ultimately, scale-up of the verified processes to generate sufficient biocatalyst for use in the biogas upgrading demonstration. Throughout the work, biocatalyst de-

velopments were made in the context of the overall project, including consideration of upgrader operational conditions, ease of biocatalyst handling, and other key requirements, such as compatibility and performance optimization with the non-volatile, environmentally-friendly AKM24 absorption solution. The function of the AKM24 absorption solution is to provide sufficient chemical "buffering" capacity to efficiently remove CO_2 from the biogas stream.

The final product is a unique, operationally versatile, particulate biocatalyst that efficiently removes CO_2 from biogas through the reaction of CO_2 with water in the presence of AKM24 absorption solution, catalysed by carbonic anhydrase entrapped in the biocatalyst, and is easily recycled and replenished for continuous biogas upgrading operation.

Biocatalyst upgrading process (Akermin and Ammongas)

The process for biocatalyst upgrading is similar to an amine based upgrading process. Biogas (app. 60% methane and app. 40% carbon dioxide) enters the absorber column. The carbon dioxide is absorbed by the process liquid (amine) and nearly pure methane leaves the absorber column and can after drying, compression and odorization, be injected in the natural gas grid. The process liquid is the heated and enters the stripper column. Here the CO_2 is stripped out of the liquid and released to the surroundings.

In the ENZUP project the design evolved during the project. For internal references in the project the development steps have been referred to as Option 0, A and B. The following sections summarize the development of biocatalyst technology since project start.

Option O: (Biocatalyst technology as described in EUDP agreement and application)

In the first conceptual design biocatalyst was applied onto absorber column packaging materials as a solid porous coating, where the carbonic anhydrase enzyme was impregnated in the coating. The biocatalysts were therefore "fixed" to the packing surface and were not dissolved as the process liquid recirculates through the absorber and stripper columns. This concept was changed, as the replacement of the biocatalyst was too difficult to do in normal operation.

Option A:

In May 2014 the project decided to make a change in biocatalyst technology from the planned use of absorber packing material coated with biocatalyst to using biocatalyst in the form of particles. The biocatalyst particles were mixed with in the process liquid and circulated in the absorber and stripper columns.

Option A: *Continuous circulation of biocatalyst in the absorber and stripper columns, include vacuum (low pressure) stripper and specialized reboiler.*

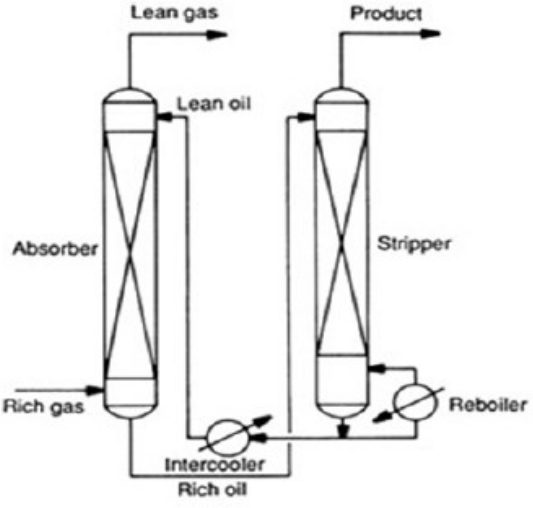
Rich gas = biogas (app. 60% methane)

Lean gas: bio methane (app. 98% methane)

Product: CO_2

Rich oil: Process liquid with absorbed CO_2

Lean oil: Process liquid stripped for CO_2



Akermin developed and performed laboratory tests during August - November 2014. However, the design and performance of the reboiler provided challenges. The concern was the risk of ruining the particles by overheating. The reboiler unit heats up the process liquid with the biocatalyst particles, so the CO_2 can be "stripped" from the liquid. The longevity of the enzymes in the biocatalyst depends, among other, on the temperature and time exposed to heat. Akermin did not succeed in designing a reboiler, where the biocatalysts were exposed to suitable temperatures. Several possibilities and mitigation strategies were evaluated. The conclusion was to change the biocatalyst approach to "Option B".

Option B:

To avoid heating up the biocatalyst particles the option B features a filter unit, separating the biocatalyst from the process liquid, so the biocatalyst is circulating in the absorber column only. The temperature in the stripper columns and the reboiler can be higher without affecting the lifetime of the biocatalyst.

Option B: *Biocatalyst circulation in absorber column only. Filter separates process liquid (right side of filter) and biocatalyst (left side of filter). Normal pressure stripper, standard reboiler design.*

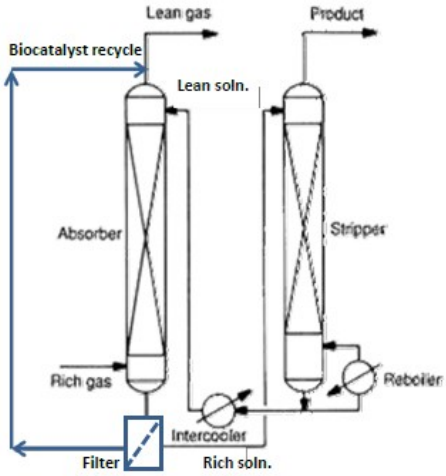
Rich gas = biogas (app. 60% methane)

Lean gas: bio methane (app. 98% methane)

Product: CO_2

Rich soln.: Process liquid with absorbed CO_2

Lean soln.: Process liquid stripped for CO_2



The development "challenge" changed to the filtration unit. The reboiler design is a standard for Amine based upgrading plant and does not provide any significant development challenges. As the concept allows higher stripper column temperature and the height of the stripper column can be reduced without affecting efficiency.

The option B had the potential to be used to retrofit a conventional Amine system requiring only minor modifications of the facility. There is significant business potential to assess the use of the technology to retrofit existing Amine plants. This could enable a high and fast market penetration.

Akermin investigated several options and ran factory tests at the sites of supplier of different filtration and separation technologies. Two technologies were selected for long term test in the Akermin laboratories: Membrane separation and a two stage process using flotation separation and a filter. Both technologies proved usable, but looking into the investment and operation costs the flotation separation proved better.

Akermin made laboratory tests of the flotation separation using a pilot scale unit in a closed loop reactor used for other biocatalyst testing to obtain as realistic working conditions as possible. The tests were successful and the full scale flotation separation unit was specified and ordered. However, it proved necessary to add a filter after the flotation separation unit to minimize the loss of biocatalyst.

System integration of upgrading plant and WWTP (HMN and BIOFOS)

The aim of the system integration of the upgrading plant in the biogas system of BIOFOS' WWTP resulted in a full integration of biogas production, existing biogas flare and gas engine (for backup), and the neighbour methanation plant.

HMN implemented the building for the upgrading plant. The building had due to environmental regulations collection system for the process liquid and biocatalyst in case of leakages, a "normal" sewage system, and a system for drain water from the gas processing room. The building also had reinforcement for the rather heavy biocatalyst-process liquid separation and a temperature regulated storage room for extra batches of biocatalyst. The ENZUP plant is constructed on landfilled area requiring pillar foundations for all foundations.

A vital part of the system integration was establishing tie-ins for biogas, electricity, waste heat (cooling for ENZUP, heat for BIOFOS), water and sewage. The system integration included the neighbour BioCat methanation plant.

HMN has in cooperation with BIOFOS developed the control strategy for the biogas system on the WWTP and defined signal exchange.

Waste Water Treatment Plant heating system alteration (BIOFOS)

BIOFOS launched in the spring 2014 a construction project with the aim to establish a new internal heating system in the WWTP. The project was initiated because all biogas from the waste water treatment process would be upgraded in the ENZUP plant instead of being used in BIOFOS' gas engine. The gas engine produces electricity for the grid, but more than half of the energy in the biogas ends as "waste" heat and is utilized in the WWTP internal heating system. The heating system ensures heating of sludge when pumped to the digesters (process heating) to ensure a satisfactory biogas production and for heating in buildings (comfort heating). The gas engine would be kept as a backup for the upgrading plant.

The new heating system is based on a reduced heat consumption with new sludge heat exchangers around the inlet and outlet of the digesters, and the utilization of waste heat from the plant's sludge incineration plants and from the upcoming biogas upgrading plant. Initially it was planned that a natural gas-fired boiler would be used as backup to in the periods when the heat from the waste water process is not sufficient.

Detailed design showed a more environmentally friendly and flexible solution with a connection to the local district heating network at Avedøre Holme. District heating is imported from the colder return pipe in the district heating network when heat is needed, and excess heat from the sludge incinerator exported to the warmer forward pipe in the district heating network.

Overall, with the implementation of the heating system the WWTP Avedøre goes from being energy consuming to become an energy-producing facility.

It is estimated that savings in the order of 2,000-2,500 tons of CO_2 per year and 25-30% reductions of emissions will be achieved (compared to 2007, the reference year for WWTP). This reduction of CO_2 emissions supports BIOFOS's goal of achieving a CO_2-neutral operation.

Dissemination activities

During the first 1½ year of the ENZUP project several oral presentations, papers and posters were presented in Danish and European gas and biogas conferences. The project team also presented articles in Danish and European gas and biogas magazines.

Please refer to Annex 1 for summary of dissemination activities.

A project website, www.enzup.com, was also launched, presenting the project and providing links to all presentations, papers, posters and articles.

The project partners hosted site visits in cooperation with the neighbour methanation project BioCat.

When the Intellectual Property issues turned up the dissemination activities were put on hold.

1.6 Utilization of project results

As the ENZUP project did not succeed in demonstrating a more energy and cost method for upgrading biogas, there are no direct project result, that can immediately influence future development.

HMN will replace the ENZUP plant with a conventional upgrading plant with the same capacity on BIOFOS' WWTP. Ammongas will be in charge of adapting the ENZUP plant to a commercial technology amine plant. The HMN upgrading plant will upgrade biogas and inject it in the natural gas grid just like the ENZUP plant, but with a less innovative technology. The plant is expected to be operational spring 2017. In the marketing of green natural gas, the upgrading facility is still a relevant and interesting project, integrating biogas upgrading and methanation with biogas production from waste water treatment, located close to a big city, and injection of bio methane in the natural gas grid.

BIOFOS has implemented a more energy efficient internal heating system supporting BIOFOS's goal of achieving a CO_2-neutral operation.

Ammongas have gained experience in the engineering and construction of the (not finalised) upgrading plant, that might beneficial for other project.

Akermin is closed down and all activities are stopped. Parts of the patents for biocatalyst carbon capture (both biogas upgrading and removal of CO_2 from flue gas) are sold to a competing company CO2 Solutions. HMN does not envision that CO2 Solutions will enter the Danish or the north European market with enzyme based upgrading processes.

Novozymes might find other way and partners for utilisation of enzyme-based approaches to CO_2 removal.

The ENZUP and co-located BioCat projects inspired two case study student projects mentored by Novozymes in the Masters of Microbial Technology program at North Carolina State University, and thereby has supported training future technology specialists and business leaders about advanced applications of biotechnology for increasing the availability of Renewable Natural Gas. BIOFOSs kindly contributed technical information on AD biogas production for one of the case study projects, titled "Anaerobic Digester Methane to Energy: A [USA] Nationwide Assessment." This is not a "published" work, but was prepared as a case study report in completion of the student project. The other project on "CO2 Utilization" is running during Fall 2016 and is not yet completed.

1.7 Project conclusion and perspective

As the ENZUP project did not succeed in demonstrating a more energy and cost method for upgrading biogas, there are no direct project result, that can influence future development.

During execution the project faced several challenges in the technology development. At the end the intellectual property challenges and the financial stress caused by these challenges were the major reasons for closing the project down prematurely.

In spite of these challenges, the project demonstrated the integration of biogas production from a WWTP, biogas upgrading, methanation and injection of the bio methane in the natural gas grid. BIOFOS WWTP's implementation of the heating system will turn the WWTP from being energy consuming to become an energy-producing facility.

Laboratory tests results produced during the course of the project support that carbonic anhydrase enhanced CO_2 separation combined with benign absorption solutions can contribute towards enabling innovative upgrading process approaches.

Annex 1 ENZUP Dissemination activities

Articles

AR0
Format: 3 page article.
Media/event: Gasteknik (Dansk Gas Forening magazine). No. 3, June 2013.
Title: Enzymforbedret opgradering af biogas
Content: Article about proposal for "Demonstration of a Novel Biogas Upgrading Technology"
Author: Henrik Rousing, HMN Gashandel A/S.

AR1
Format: 1 page article.
Media/event: Forskning i Bioenergi, Brint og Brændselsceller. No. 40, February 2014.
Title: Fra vindmøllestrøm til grøn gas".Content: Brief project descriptions of the EUDP funded "Demonstration of a Novel Biogas Upgrading Technology" and the ForskEL funded Power-to-Gas BioCat2" project.
Authors: Torben Skøtt, Biopress.

AR2
Format: 3 page article.
Media/event: Gasteknik (Dansk Gas Forening magazine). No. 2, April 2014.
Title: Renseanlæg Avedøre kan bidrage til mere grøn naturgas
Content: Article about biogas production on BIOFOS waste water plant, the EUDP funded "Demonstration of a Novel Biogas Upgrading Technology" and the ForskEL funded Power-to-Gas BioCat2" project. (same basic content as AR3)
Authors: Dines Thornberg, BIOFOS A/S & Henrik Rousing, HMN Gashandel A/S.

AR3
Format: 2 page article.
Media/event: danskVAND (DANVA magazine). No. 3, June 2014.
Title: BIOFOS bidrager til mere grøn naturgas
Content: Article about biogas production on BIOFOS waste water plant, the EUDP funded "Demonstration of a Novel Biogas Upgrading Technology" and the ForskEL funded Power-to-Gas BioCat2" project. (same basic content as AR2)
Authors: Dines Thornberg, BIOFOS A/S & Henrik Rousing, HMN Gashandel A/S.

AR4
Format: 4 page article.
Media/event: Gas for Energy. No. 2 May 2015.
Title: Biogas - more cost effective upgrading using biocatalyst
Content: Article about the EUDP funded "Demonstration of a Novel Biogas Upgrading Technology". Biogas and bio methane system, enzymatic upgrading and grid injection
Author: Thomas Hernø, HMN Gashandel A/S.

AR5
Format: 4 page article.
Media/event: Om Energi (Energi Net magazine). No. 2 September 2015.
Title: Det er energioptimering der rykker
Content: Article about the EUDP funded "Demonstration of a Novel Biogas Upgrading Technology". Author: Energinet.dk with input from BIOFOS and HMN Gashandel A/S.

Adjacent publication inspired by the commercialization intentions of the ENZUP collaboration

S. Salmon and A. House, "Enzyme-catalyzed solvents for CO2 separation," in Novel Materials for Carbon Dioxide Mitigation Technology, F. Shi and B. Morreale, Eds., Amsterdam, Elsevier B.V., 2015, pp. 23-86. DOI: 10.1016/B978-0-444-63259-3.01001-6.
Notes: S. Salmon was the Novozymes Project Manager in the ENZUP project and A. House contributed to the project. Although ENZUP is mentioned briefly on page 54 of the Chapter, the writing of the book chapter "Enzyme-catalyzed Solvents for CO2 Separation" was very much inspired by the goal to make past research in enzymatic CO_2 scrubbing more visible, and thereby create more freedom to move the technology forward commercially.

Conference presentations and posters

CP1
Format: 22 slide presentation.
Media/event: Thirteenth Annual Conference on Carbon Capture, Utilization & Storage. 28 April - 1 May 2014, Pittsburgh, Pennsylvania, USA.
Title
Content: Field Pilot Results of a Novel Biocatalyst-Enabled Process for CO2 Capture
Author: Sean Black, Akermin Inc.

CP2
Format: Presentation (1 slide about ENZUP)
Media/event: Meeting in Washington DC sponsored by the Coal Utilization Research Council (CURC). 12 June 2014, Washington DC, USA.
Title: Advanced Coal Technology Showcase
Content: Field Pilot Results of a Novel Biocatalyst-Enabled Process for CO2 Capture
Author: Sean Black, Akermin Inc.

CP3
Format: 10 page paper (CP3a) & 25 slide presentation (CP3b)
Media/event: International Gas Union Research Conference 2014, 17-19 September 2014 in Copenhagen, Denmark
Title: Biogas upgrading using biocatalyst technology
Content: Paper on biogas upgrading using Akermins biocatalyst technology
Authors: Sean Black & John Reardon Akermin, Inc. Henrik Rousing HMN Gashandel A/S

CP4
Format: 1 page poster and 7 page paper (CP4a) & 12 slide presentation (CP4b)
Media/event: International Gas Union Research Conference 2014, 17-19 September 2014 in Copenhagen, Denmark
Title: The Avedøre Project - How to find renewable biogas sources and integrate them in gas grid by upgrading and methanation with new technologies
Content: Poster and paper on EUDP funded "Demonstration of a Novel Biogas Upgrading Technology" and the ForskEL Power-to-Gas BioCat2" project.
Authors: Dines Thornberg, BIOFOS & Henrik Rousing, HMN Gashandel A/S

CP5
Format: 6 slide presentation
Media/event: Methanisering af CO2 i Biogas, 11 December 2014 in Lemvig, Denmark
Title: Visioner for Biogas og Projekter vedr. lagring af vindenergi
Content: Presentation on methanation
Author: Henrik Rousing HMN Gashandel A/S

CP6
Format: Poster
Media/event: REGATEC 2015, 7-8 May 2015 in Barcelona, Spain
Title: Enzymatic Upgrading of Biogas. How Renewable Resources can be integrated in the Natural Gas Grid
Content: Presentation on upgrading using Akermins biocatalyst technology and biogas system
Author: Thomas Hernø, HMN Gashandel A/S

CP7
Format: 30 slide presentation
Media/event: Dansk Gas Forening - Gastekniske Dage, 12-13 May 2015 in Billund, Denmark
Title: ENZUP – Enzymbaseret opgradering
Content: Presentation on upgrading using Akermins biocatalyst technology and biogas system
Author: Thomas Hernø, HMN Gashandel A/S

CP8
Format: 6 slide presentation (and 30 slide background presentation)
Media/event: WGCPARIS 2015, 1-5 June 2015 in Paris, France.
Title: Enzymatic Upgrading of Biogas and how Renewable Resources can be integrated in the Natural Gas Grid Content: Presentation on upgrading using Akermins biocatalyst technology and biogas system
Author: Thomas Hernø, HMN Gashandel A/S

CP9
Format: 12 slide presentation
Media/event: EUBCE 2015, 1-4 June 2015 in Vienna, Austria.
Title: Enzymatic Upgrading of Biogas and how Renewable Resources can be integrated in the Natural Gas
Content: Presentation on upgrading using Akermins biocatalyst technology
Author: Henrik Rousing, HMN Gashandel A/S

CP10
Format: 17 slide presentation
Media/event: 12th IWA Leading Edge Conference on Water and Wastewater technologies, 1-3 June 2015 in Hong Kong, China
Title: Biogas Upgrading and Methanation projects at WWTP Avedøre
Content: Presentation on biogas and heating system and ENZUP and BioCat project
Author: Dines Thornberg, BIOFOS A/S