Final report

Project title	MeGa-StoRE 2 phase 1
Project identification (program abbrev. and file)	ForskEL 12270
Name of the program which has funded the project	ForskEL
Project managing company/institution (name and address)	DTU Mekanik Danmarks Tekniske Universitet Institut for Mekanisk Teknologi Nils Koppels Allé Bygning 404 2800 Kgs. Lyngby
Project partners	Technical University of Denmark – Mechanical Engineering GreenHydrogen.dk Elplatek A/S NGF Nature Energy
CVR (central business register)	30060946
Date for submission	31-8-16

0. Resume - deliveries and findings

As stated in the project application, the outcome of the introductory Phase 1 should be a design of a purifier and methanation unit ready to be implemented at a much larger scale in the following Phase 2. It is stated, that product specification and system architecture shall be approved as a prerequisite for startup of Phase 2.

The application for the MeGa-StoRE project also stats that the project should commence January 1, 2015, unfortunately the project first started three months later. This has in addition to other delayed delivery of equipment resulted in the fact that the project has been delayed three months. However, it is not expected that the delay during Phase 1 will cause any delay for the final report for the MeGa-StoRE 2 project. This is a result of many other project activities been handled earlier than originally planned. No additional costs then presently are expected.

All conceptual material for approval of Phase 1 are now available as a kick off for Phase 2. This is reported below.

Overall, the main assets of the project and their compliance with the time schedule can be summed up as:

Gas laboratory
The gas laboratory has been developed even more than what was expected at this point of time in the project. The infrastructure for piping's etc. has been defined and is ready to be used.

Gas cleaning
Experiments on the TAYTAY reactor has proved, that the electrocatalytic gas cleaning process works with success beyond expectations under the MeGa-StoRE 2 project.
It is expected that the continuous experimentation on the TAYTAY reactor will results in enough information to draft an up-scaled version for 15 Nm^3/h biogas.

Methanisation reactor
This test shows that the new methanisation reactor is capable of converting CO_2 into methane in one-step. The graph proves methane in the exit gas increasing up to the desired level, indicated that the conversion has worked and will be working efficiently. Longer tests for further optimization of the methanisation unit will be carried out during Phase 2. Given the primary test performed in the methanisation reactor, it is clear that the reactor is performing as expected. Further test will concentrate on heat distribution in the reactor and higher gas flows.

- Product design

The final module size has been found in close collaboration with a string of sub suppliers. The product design is very mature and ahead of schedule.

- Electrolyzer

The final design of the prototype has been tested and the design of the downsized electrolyzer has been finalized. In the next face the focus will be on getting the different approvals for the electrolyzer and the construction of the electrolyzer that is going to be installed at NGF.

The MeGa-StoRE 2 - phase 2 - will benefit from the results of this project, especially knowledge as acquired and the sub supplier system constructed.

Although the technology is still approximately two years from being ready for commercialisation, a very keen interest from potential customers as technology- and industry partners has been observed.

The overall strategy will be to deliver turnkey solution through industry partners and system integrators to avoid any challenges with up-scaling of business activities. Countries like Denmark and Germany have ambitious plans for methanation and based on information from a potential partner in Germany, the potential market for MeGa-StoRE in Germany is estimated to be +2000 biogas plants. Our modular concept appeals to smaller biogas plants (low initial investment) and the concept will distinguish clearly from competitors like Linde, MAN and Topsøe, who all focus on large, heavy-duty methanation plants.

1. Project details

1.1 Short description of project objective and results

English version:

The MeGa-StoRE 2 phase 1 project have:

- Founded a gas laboratory in Horsens
- Designed, constructed and tested the methanisation reactor
- Invented, developed and tested an electrocatalytic gas cleaning method
- Formulated and planned the module based final design

The gas laboratory is centralized around a state-of-the-art gas chromatograph. This analysis equipment have been essential in developing and testing the completely new electrocatalytic gas cleaning method.

The methanisation reactor have been designed, constructed and tested.

A vital part of the MeGa-StoRE project is the module based philosophy with 90-95% standard components. In the first phase of the MeGa-StoRE 2 project, effort has been made to find the right sub suppliers to lift this task. Together with these companies, the module size have been developed and finalized.

Danish version:

MeGa-StoRE 2 fase 1 projektet har:

- Grundlagt et gaslaboratorie i Horsens
- Designet, konstrueret og testet metaniseringsreaktoren
- Opfundet, udviklet og testet en elektrokatalytisk gasresningsmetode
- Formuleret og planlagt det endelige modulbaserede design

Gas laboratoriet er centraliseret omkring en state-of-the-art gaskromatograf Dette analyse-udstyr har været essentielt i udviklingsarbejdet omkring den helt nye elektrokatalytiske gasrensningsmetode.

Metaniseringsreaktoren er blevet designet, konstrueret og testet.

En vital del af MeGa-StoRE projektet er den modulbaserede filosofi, med 90-95% standardkomponenter. I den første fase af MeGa-StoRE 2 projektet, er der blevet lagt stor vægt på at finde de rigtige underleverendører, der kan være med til at løfte denne opgave. Sammen med disse virksomheder er størrelse på modulerne blevet udviklet og endeligt bestemt.

1.2 Objects met during execution of phase 1 in the project

The MeGa-StoRE 2 phase 1 project is a precursor for the MeGa-StoRE 2 - phase 2 - project. Therefore, the goals and results of phase 1 are closely linked to the overall MeGa-StoRE 2 project. Thus, this *final* report of a phase 1 project reports the *progress* of the overall project.

As mentioned in the brief resume, the gas laboratories founded in Horsens is central to the overall project, and has been an important goal of this project. The laboratory was founded in a location with no background in gas technology. Therefore, the laboratory was designed from scratch, which has been an advantage as the newest state-of-the-art equipment for advanced analysis of gasses have been installed, configured and tested. The time consumed to construct that laboratory may be considered an inevitable disadvantage; however, it is an investment that is expected to pay off.

The methanisation reactor have been designed, constructed and tested. This reactor combines several technologies to create a chemical reactor suited for this exact application. The reactor features a new control method, as a thermographic camera can monitor the temperatures inside the reactor. Combined with an in depth knowledge of heat transfer inside the reactor, the information from the thermographic camera can be used to detect hotspots in the reactor. Due to the design of the reactor, these hot spots can be eliminated.

The methanisation reactor, upon finalizing the design in December 2015, was ordered at the Danish company GA Rustfri A/S. Unfortunately, upon inspection by Inspecta, it was found that GA Rustfri did not have the required certificates/qualifications to construct the reactor. Instead, GA Rustfri A/S had to contact another Danish company, Rutek A/S, to construct the reactor. For the MeGa-StoRE 2 phase 1 project, this resulted in a delay of up to more than three months in receiving the reactor.

The gas cleaning method in the first MeGa-StoRE project was a great success, It could have been scaled up and probably applied, but the goal was to be able to clean sour gasses of bad quality with reduced cost. Therefore, another cleaning method had to be devolped, and in the MeGa-StoRE 2 - phase 1 - this new method has been developed and tested. State of the art industrial cleaning methods use mainly adsorption techniques which are very costly for sour gasses of this quality. Therefore, the aim of the MeGa-StoRE project was to develop a new method. In the spring of 2016, this new method proved to work under laboratory conditions, and an up-scaled apparatus was constructed.

Great effort has been made to find the optimal sub suppliers and involve them in the project. In appendix 1, a list of Danish and German sub suppliers been involved in the project can be found. Several of these have found the project so interesting and promising that the companies have contributed to the project. Mainly German giants, Rittal and ODU have contributed to the project with several man-hours and seminars held for the MeGa-StoRE project in Germany have been sponsored.

The philosophy of MeGa-StoRE is what has drawn the attention of the companies. Furthermore, the philosophy of a module-based plant is of great importance. In close collaboration with the main sub suppliers, the final module size have been found at the MeGa-StoRE seminar hosted by Rittal, where the whole MeGa-StoRE group, 5 representatives from ODU and 9 from Rittal were present.

It has been the experience of this project, that when presenting the philosophy and the project to sub suppliers, the response has been overwhelming, first of all at Rittal and ODU. The philosophy states, that 90-95% of the components used should be standard components. Thus the last 5-10%, i.e. the cleaning unit and the design of the methanisation reactor, are the core unit of new investigations and will be kept secret to be patented.

The electrolyzer for the MeGa-StoRE project is going to be based on the HyProvide™ 250 platform (250 kW electrolyzer system), but the electrolyzer will be a downsized module, due to the capacity requirements and the financial aspect. A prototype of the HyProvide™ 250 has been tested in terms of efficiency, dynamic operation, gas quality etc. Based on these tests, the design has been finalized. The next phase will focus on compliance with the relevant European safety directives, e.g. the Pressure Equipment Directive and the Machine Directive. For the MeGa-StoRE project, the HyProvide 250 module and all necessary auxiliary appliances will be built into a 20-foot container in order to provide a turnkey hydrogen producing plant.

The interest for the MeGa-StoRE concept in the market is huge and the first commercial meetings with potential customers and partners in primarily Denmark and Germany have been initiated. The reaction has been very positive, and MeGa-StoRE is seen as a shift in paradigm that will allow incremental investments and be a realistic possibility for even small and medium sized biogas plants in the future. Feedback from customer and partner meetings on technology, operations and economy is all taken into consideration in the design process, where the technology is now being moved out of the lab test stage to be developed to deliverable, commercial products.

1.3 Project objectives

The technology to be optimized and up scaled in this project can create a connection from the electric grid to the gas grid. In the transition towards an energy system with increasing amount of wind power and decreasing natural gas resources, the technology can secure the gas supply by 2nd generation upgrading of biogas to be fed into the gas grid. The gas grid is connected to large underground gas storages. Therefore the technology potentially also offers a storage capacity of wind power equivalent to several months of gas consumption. Besides that, utilizing the about 35% CO_2 content in the biogas, the utilization of the biomass resource feed into the biogas reactors is increased by 50%, when the CO_2 content in the biogas is methanized by reaction with hydrogen to form CH_4, methane:

$$CO_2 + 4H_2 \Rightarrow CH_4 + 2H_2O \quad \text{(the Sabatier process)}$$

This is an important advantage of the technology, because the future demand for biomass in the energy sector will increase and be the bottleneck for the renewable energy supply.

The technology, which is to be optimized, long-time tested and up scaled in this project, is an effective and potential inexpensive way to upgrade biogas, in order to obtain a gas quality similar to natural gas and store it in the natural gas system. Subsequently it can be used in decentralized combined heat and power plants (CHP) as back up for solar and wind power, or as fuel in the transport sector.

For natural gas or vehicle fuel standards to be met, removal of CO_2 and some of the impurities is required, as CO_2 dilutes the energy content of the biogas and the impurities are damaging to the systems in which they are used. Until now, upgrading of biogas to these standards has merely focused on removal of CO_2 by amine extraction and H_2S by using different biological based technologies with bad removal of hydrogen sulphide (1st generation upgrading). However, it will be more advantageous to exploit the total carbon resource in the biomass by transforming the CO_2 content in the biogas to methane in a Sabatier process.

The technology involves two sub processes. A purification of the biogas where H_2S and other damaging compounds is removed, followed by a methanisation where CO_2 reacts with H_2 to form CH_4.

Project results and dissemination of results

Task 1.1 Product specification

1.1.1 Specification of Technical data according to roadmap

The methanisation reactor was delayed, but now, the reactor has been tested in order to evaluate the conversion performance. The tests show a capability of converting CO_2 into methane with conversion rates above 97%.

In the road map, it was proposed that the reactor size and its capacity should be increased over time. With the module based design being investigated, however, the increase in size and capacity can be achieved much faster than the road map initially indicated. With over 90 % standard components and a modular based system, scalability is in focus. Furthermore, after much discussion with sub suppliers, certain module sizes have been chosen.

1.1.2 Development of system architecture

As part of the philosophy of the project, the system should resemble that of a server park, not only in appearance, but also in configuration. Instead of having a single, large, reactor this project aims to have several, smaller, reactors. In fact, the modularization should concern not only the methanisation reactor, but also the cleaning unit, compressor etc. In this way the overall system can continue with no down time in case of failure of subsystems. Furthermore the system is designed so that *hot swap* with a new component will be possible. Also, another advantage is, that the failed component can be returned to the workshop and be fixed, avoiding *in situ* repair.

As mentioned earlier, the aim is to have 90-95% standard components; however, this is not only the case for hardware, but also for software. The software for control of a server park is largely what is required for managing the system for this project.

1.1.3 Definition of module sizes, to meet different system sizes

A central part of the first phase has been to determine the module sizes. In close collaboration with the sub-suppliers, this size has been determined to fit into the philosophy of the project, i.e. 90-95 % standard components. The module sizes have been determined to be a standard cabinet from Rittal, i.e. a 60cm x 60cm cabinet with a height of 220 cm. With this space, the cleaning units, methane reactor, compressors etc. The modules are compiled in a non-ISO 20 feet container that can hold 18 cabinets. An important design parameter is the ability to transport the container by truck, which is ensured, also for the non-ISO container. Comparing with an ISO container, the non-ISO container allows for easy maneuvering inside the container due to the bigger volume.

Task 1.2 Establishing of online gas analyzing for research

1.2.1 Specification of equipment and measurement procedure

A central part of the MeGa-StoRE project has been to clean the gas innovatively. Both the gas cleaning unit for the MeGa-StoRE 1 POC container and the new electrocatalytic process are designed and developed within the projects. As the catalysts require a completely clean gas, especially from hydrogen sulphide, it is of uttermost importance to know the gas composition after these new cleaning processes. During MeGa-StoRE 1, the gas was cleaned so efficiently, that no hydrogen sulphide in the gas could be detected afterwards; which corresponds to hydrogen sulphide in the order of 10 ppb. In order to fully understand the processes, including limitations and abilities, knowledge about the gas composition is central. Thus, a gas chromatograph (GC), see Figure 1, was acquired for the project. Generally, GCs can be assembled in different ways to give the best possible analysis tools for the compositions at hand. Two main features were selected; a detector for the general composition and a detector for precise measurement of the sulphur content. The two detectors, including the three columns, are schematically presented in Figure 1, together with the rest of the interior of the GC.

Thermal Conductivity Detector

The thermal conductivity detector (TCD) is for the Agilent 7890B Series. The detector consists of two columns, where the first column is used to separate the different compounds in the gas, and the second is used for storing some of the gasses following separation.

The working principle is that the different compounds in the gas travels through the column at different velocities. In principle, the TCD consists of two electrodes and a parallel tube. The gas for detection is heated by the first electrode, and the heat received by the gas is measured by the second electrode. The two electrodes measure the resistance and can thus detect the heat conduction as a function of the resistance. A carrier gas is used, and thus a continues parallel detection of the carrier gas is done to correct the signal.

Sulphur Detector

The equipment used in this GC is an Agilent Sulfur Chemiluminescence Detector duel plasma system. The detector is based on chemiluminescence, i.e. the emission of light following a certain chemical reaction, and has a sensitivity of < 0.5 pg S per second. The detector consists of two different reaction chambers, one preparing the sulphur containing gas, and a second where the light emitting reaction takes place. In the first chamber, the different sulphur compounds in the gas (mostly SO_2 and H_2S) is converted to SO. In the second chamber, ozone is added to form Sulphur gas compounds with exited Sulphur that will emit light. This light is then processed via photomultipliers and detected. As single photons, corresponding to single sulphur atoms, can be detected, the sensitivity of the equipment is very high, as atoms are, literally, counted.

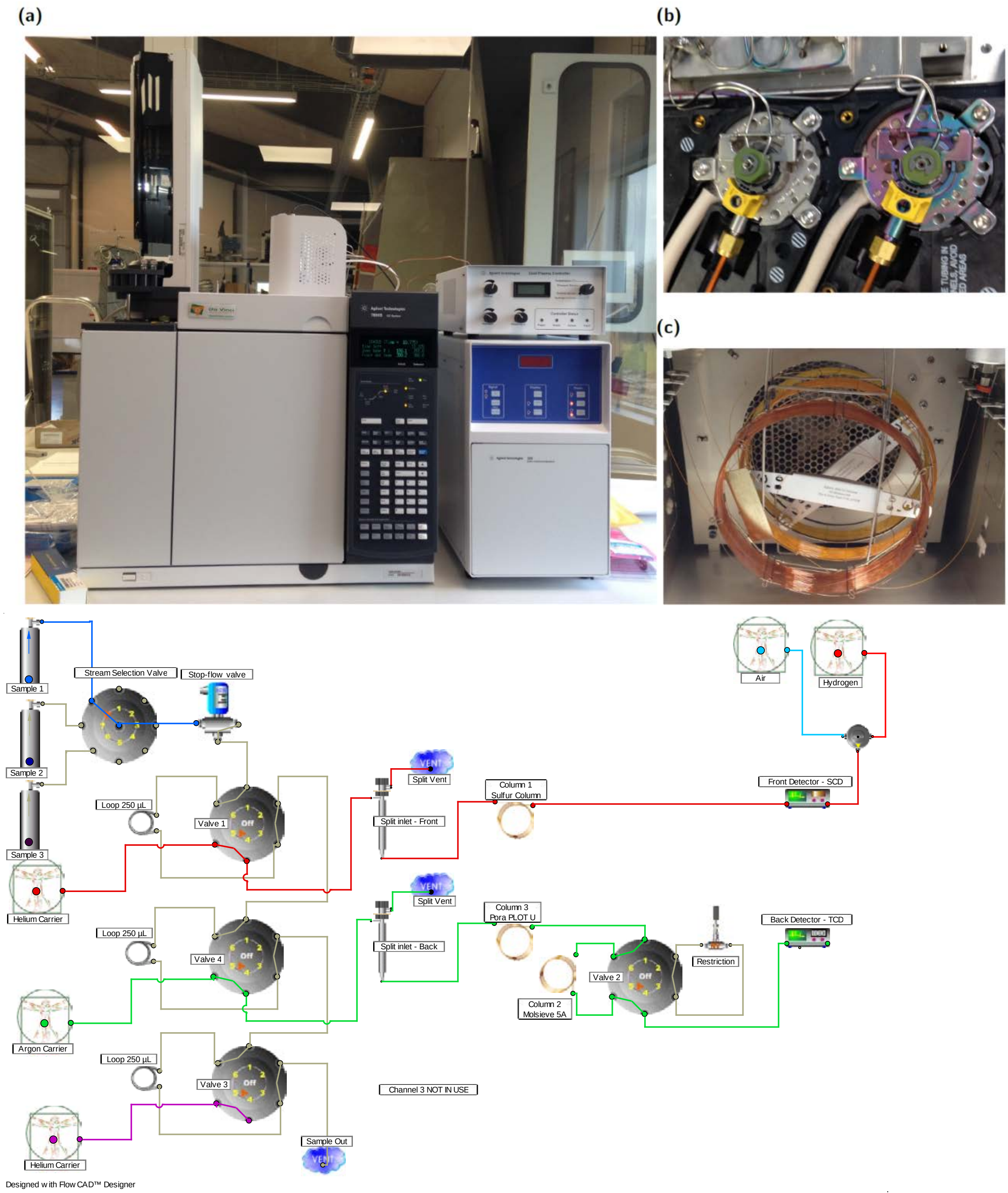

Figure 1: Top: a) The gas chromatograph. b) Valves, with the right valve having the distinctive color of the surface treatment Sulfinert. c) The three columns in the gas chromatograph. Bottom: The inside of the gas chromatograph schematically presented. Two detectors, the sulphur and the thermal, are present, with the potential to add a third.

Figure 2: The gas laboratory in Horsens. The fume cabinet is used for the experiments with the gas cleaning systems. The gas chromatograph can be viewed in the bottom right corner, close to the working area, but safely behind glass as to ensure no accidents are to harm it.

Figure 3: Top: The gas source for the laboratory, placed outside. Bottom: Safety has been of great concern in the design of the laboratory, all in compliance with the local fire department. Especially the rampart, securing the neighbours, was considered a great addition.

1.2.2 Installation and training of personnel for gas analyses.

Flexible and extensive gas infrastructures have successfully been established in the laboratory in Horsens. Central parts of the tubing infrastructure can be seen in Figure 4, where the inlet tubes for the GC and the control cabinet for gasses into the laboratory is shown.

There are 16 inlets to the GC, which allows for in depth analysis of the gas compositions at different places in the process. In Figure 5, the GC and the tubes connected to it, is presented. Here, 9 tubes enter the GC from the experimental set-up (4 from gas cleaning, and 5 from the methanisation reactor). This has left 7 inlet tubes for other gasses, e.g. reference gasses and other gases for analysis. Reference gasses also has to enter the GC, making it more complicated than presented in Figure 5. Initially, four inlets to the GC have been kept only for reference gasses; however, it is possible to extend this number. Furthermore, 4 tubes enters the GC with carrier gasses for the different analysis programs.

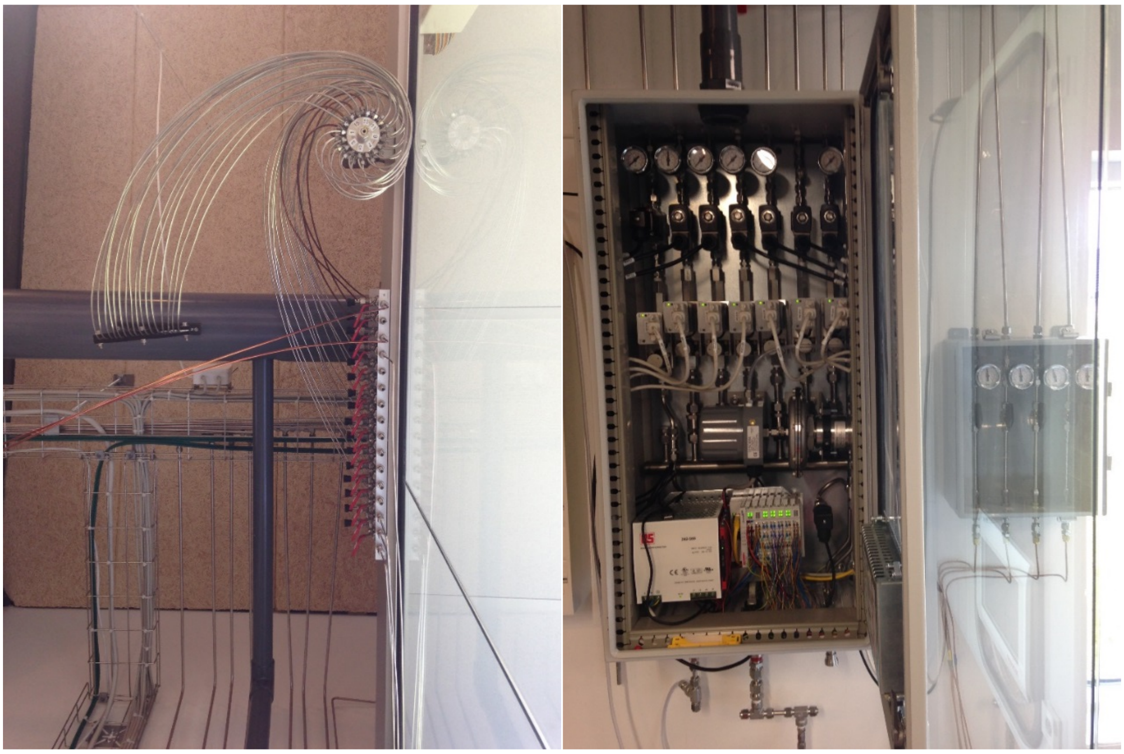

Figure 4: Left: Tubing work for the gas chromatograph, as seen from below. Right: The gas control cabinet that controls the input of gasses from the outside source.

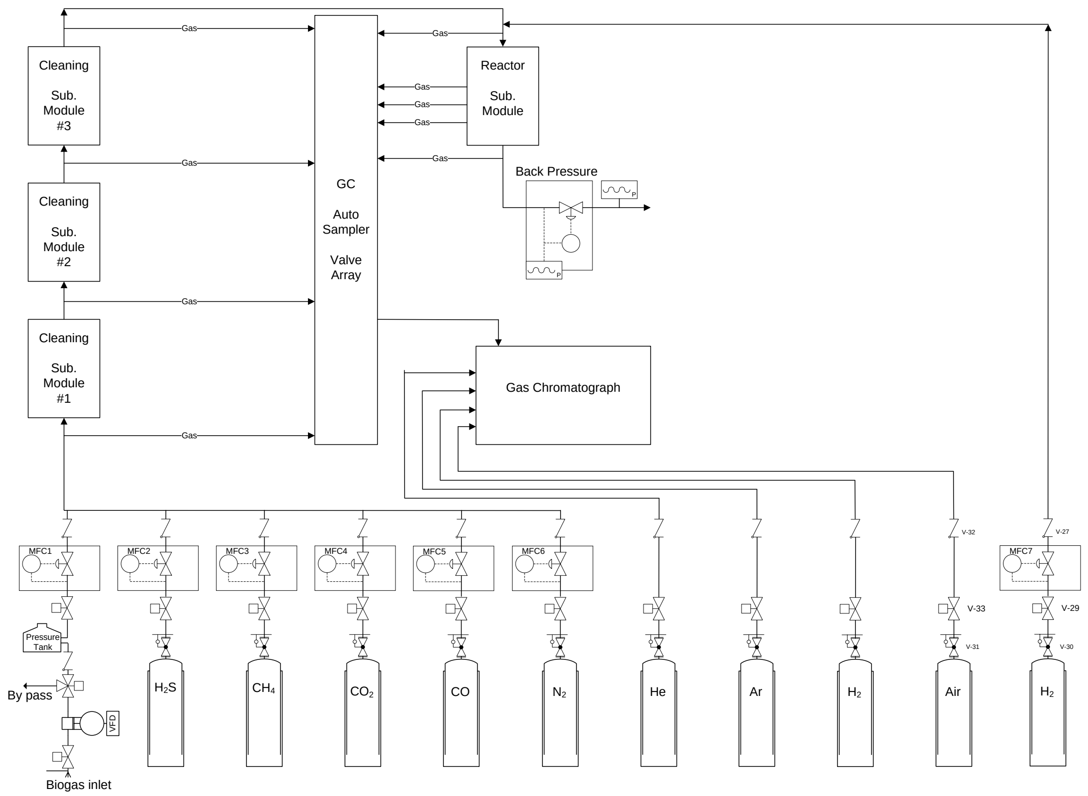

Figure 5: The position of the gas chromatograph and the other modules in the laboratory set up.

The supplier of the GC solution, Da Vinci Laboratory Solutions B.V., has preformed training of personnel for gas analyses at the installation time. This course will be followed up by training from Agilent Technologies in September 2016.

Task 1.3 Research of different design considerations for cleaning unit

1.3.1 Research alternative cleaning process

In MeGa-StoRE 2 a regenerative technology has been established, which can remove very large amount of impurities containing H_2S, mercaptanes, silanes, alcoholes, forming H_2SiO_3 compound and free S and CO_2. The new method makes it theoretical possible to remove more than 2000 ppm H_2S. Experiment already shows that a gas containing 1600 ppm can be re-duced in one step to less than 80 ppm. There is principally no problem from a theoretical point of view to remove significant higher level of H_2S - 10.000 ppm has already been discussed with hydrocarbon specialist in the US and will probably be tested already next year on gas wells in the US. Hydrocarbon specialist from the US has already predicted the new regenerative gas cleaning technology TAYTAY (given name) for the greatest innovations ever in cleaning of ex-tremely sour gasses like biogas. The team expects that the H_2S content in the gas can be brought down in the ppb area already in one-step, when the catalyzer is further optimized. An-yway, it is the intension to use a two-step process, where the last step is similarly to the Lemvig project. The improved performance shows that this is probably not necessary for Nature En-ergy project. It is important to notice, that the new gas cleaning technology have a cost, which is probably only 10 % or less of the present absorber technologies. To run a Sabatier high effi-ciency Sabatier catalyzer it is important to be about 10 ppb.
There is absolutely no doubt that the project team has the technology and skill-set to build an up scaled cleaning unit - which also is explained by the large interest from the US.

1.3.2 H_2S cleaning (10 bar)

The cleaning unit works under a pressure of 0.5-1 bar, mostly due to the combination of technologically challenges at higher pressures, and the fact that it had to be pressurized for analysis purposes. A 10 bar pressurized cleaning unit is not expected due to the challenges in approving the equipment, higher cost and compressor capacity to withstand the dirty biogas. However, the final pressure of the gas cleaning system have yet to be determined, although a pressure of 0.5-1 bar may prove to be the smartest solution.

1.3.3 Optimization and upscaling of cleaning unit

The experimental investigation of electrocatalytic gas cleaning started in September 2016. Since then, a reactor (TAYTAY) for laboratory scale experiments have been constructed and tested in laboratory environment. The initial results have been positive, as removal of 95 % of H_2S has been proved possible only using a 1. Step reactor. The present result confirms that the present industrial applied and very expensive state of the gas cleaning absorber technology can be replaced by the TAYTAY technology. It has always been our intention to use a two-step technology. An overview of the principle of the technology is graphically presented in the below Figure 6.

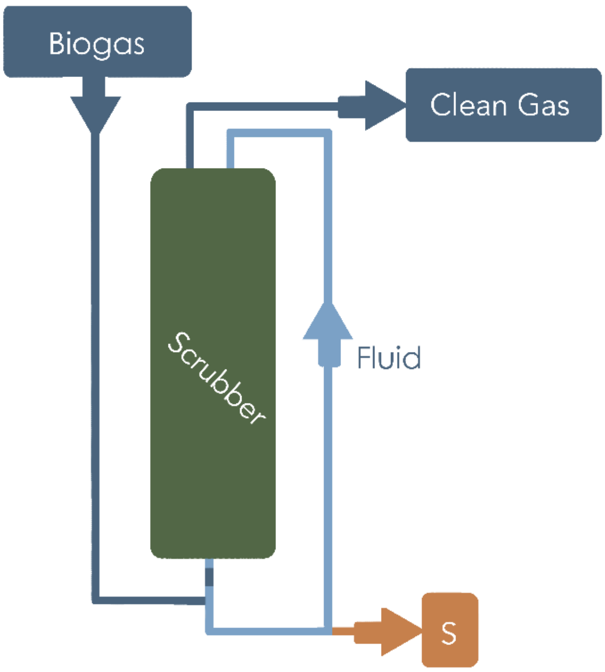

Figure 6: The electrocatalytic gas cleaning system. Gas and liquid is mixed over a catalyst. The H_2S is oxidized and leaves H_2 in the gas and elemental sulphur in the liquid.

1.3.4 Selection of measurement concept for cleaning unit (control, monitoring and protection)

Initially, the cleaning unit is monitored primarily by the gas chromatograph, but also by measuring the current that flows through the system. In the final design, the same two monitoring systems are expected to be used, although, the gas analysis will be performed only after the cleaning by another measurement technique due to the location of the gas chromatograph. H_2S is not only a corrosive gas it is also very toxic. Therefore, the safety is of great concern when operating new technologies involving this gas. The experiments have all been performed within a fume cabinet, and due to the distinct odor of the gas, any leaks outside the fume cabinet have been detected manually and resulted in complete evacuation of the laboratory. H_2S alarms exist for this exact purpose and these will be installed in the final design. The measurement in the final system will be carried out by a "MRU - SWG 100 Biogas Analyzer", where it is possible to continuously measure: O_2, CO_2, CH_4, H_2S, H_2 and CO even CO probably not will be present working with biogas. But in future experiment with gas from thermal gasification it will be relevant to have CO measurement involved.

1.3.5 Design review

Reactor Design

In Figure 7, the TAYTAY reactor is shown. The set-up resembles the commercial gas scrubbing systems, as only the equipment for applying voltage (not showed on the Figure) is added. The catalysts and liquid, however, differs greatly from commercial systems. The reactor has been constructed using corrosion resistant materials due to the gasses and chemicals being handled.

Initial Results

The latest results from the TAYTAY reactor are presented in Figure 8. An input gas (model gas) consisting of 1600 ppm H_2S in 90 % CO2 and 10 % N_2 is cleaned down to 80 ppm H_2S. The detailed process parameters are presented below. Several important parameters have not been tested yet. However, it is estimated that upon calibration, the gas can be completely cleaned in one step. So far, only gas flows of 400 L/h have been tested, and thus, the capacity of the TAYTAY reactor has yet to be determined. Although the gas cleaner catalyzer has not been optimized the gas cleaning method has shown surprisingly positive results and the results already obtained are sufficient to satisfy requirements under the MeGa-StoRE 2 project. The TAYTAY reactor seems to have a much large efficiency and is able to treat much large amount of gas compared to the size of todays technology applied by industry. The second step has already been tested in the Lemvig project been able to reduce H_2S contaminants to less than 10 ppb.

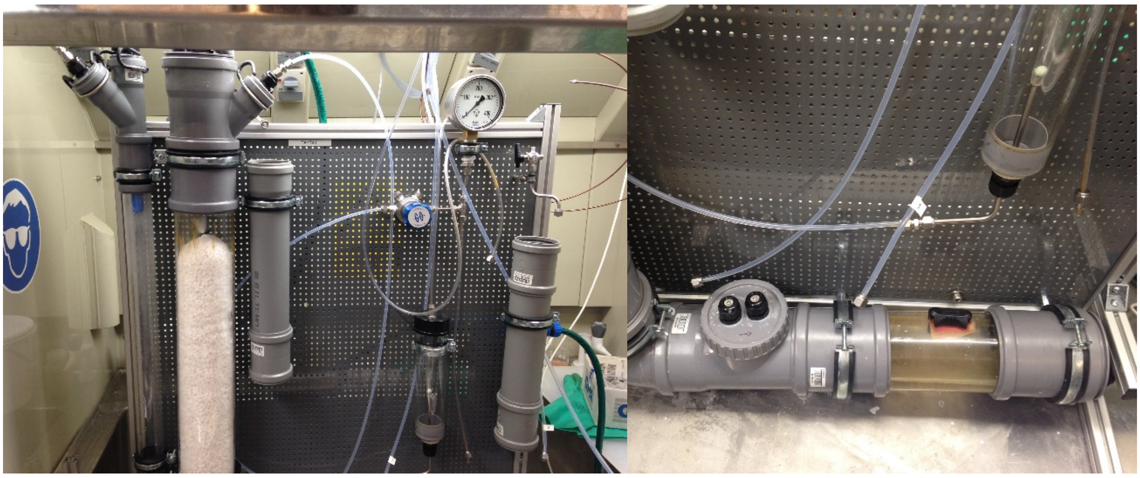

Figure 7: (left) The top part of the TAYTAY reactor. The pipes allow for visual inspection of the catalysts while operating. (right) The bottom part of the TAYTAY reactor. Another piece of visible pipes allows for visual inspection of the liquid. The pumping equipment is mainly situated on the back side of the set-up.

Outlook

Experiments on the TAYTAY reactor has proved that the electrocatalytic gas cleaning process works as expected. Within 2 months, it is expected that the continuous experimentation on the TAYTAY reactor will results in enough information to draft an up-scaled version for 15 Nm^3/h biogas. Thus, the electrocatalytic gas cleaning system is expected to be finalized with success beyond expectations under the MeGa-StoRE 2 project and will probably be commercialized before MeGa-StoRE 2 finish.

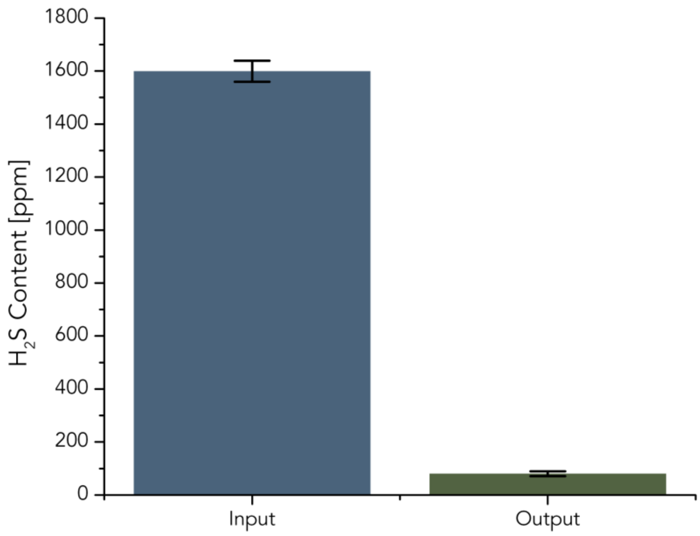

Figure 8: Latest results from the TAYTAY reactor. A gas of 1600 ppm H_2S is cleaned down to 80 ppm H_2S.

Process Parameters
- Voltage/Current: 8.6 V/2.8 A
- Gas flow: 400 L/h
- H_2S content (input): 1600 ppm
- H_2S content (output): 80 ppm
- Gas hourly space velocity (GHSV) of 100/h

1.3.6 Compliance review

Although the electrocatalytic gas cleaning technology is completely new, the technology has been assembled rather quickly. Following the first positive results, the understanding and development of the technology have been one of the main focusses of the group, which has resulted in the many different designs.
The cleaning unit was slightly behind the time schedule; however, the last results from experiments shows , that the cleaning unit delay has been catched up avoiding delays in the phase 2 project. A PhD student has been employed in this area of the project and very much focus is put to that part – because of a huge commercial interest.

Task 1.4 Research of different design considerations methanation unit

1.4.1 Optimization and upscaling of reactor design

The methanisation reactor has been designed to be thermographically controlled with the possibility to eliminate hotspots. The up-scaled methane reactor is a central part of the MeGa-StoRE 2 - Phase 1. Changing dimension and shape of a reactor with a reaction been very sensible to temperature is complicated; especially when the reaction is exothermic. To be able to monitor the catalyst while the process is running a thermographic camera was introduced. The reactor has been scaled up with a factor 10 from the size of the reactor used in MeGa-StoRE 1. In the first generation, the reactor was actually made of four parallel reactors with a outer diameter of 25mm and a length of 400mm, each with catalytic volume of approximately 125ml, giving a total of 500ml catalyst. The new reactor has an inner diameter of 250 mm and a high 600mm, with a catalytic volume of 5000ml. The bed high in the catalyst is approximately 120mm, and it is possible to extend this due to the total height of the reactor.
The first generation of reactor was able to upgrade approximately 1 Nm^3 biogas pr. Hour and the second generation will be able to upgrade approximately 10 Nm^3 biogas pr. Hour.

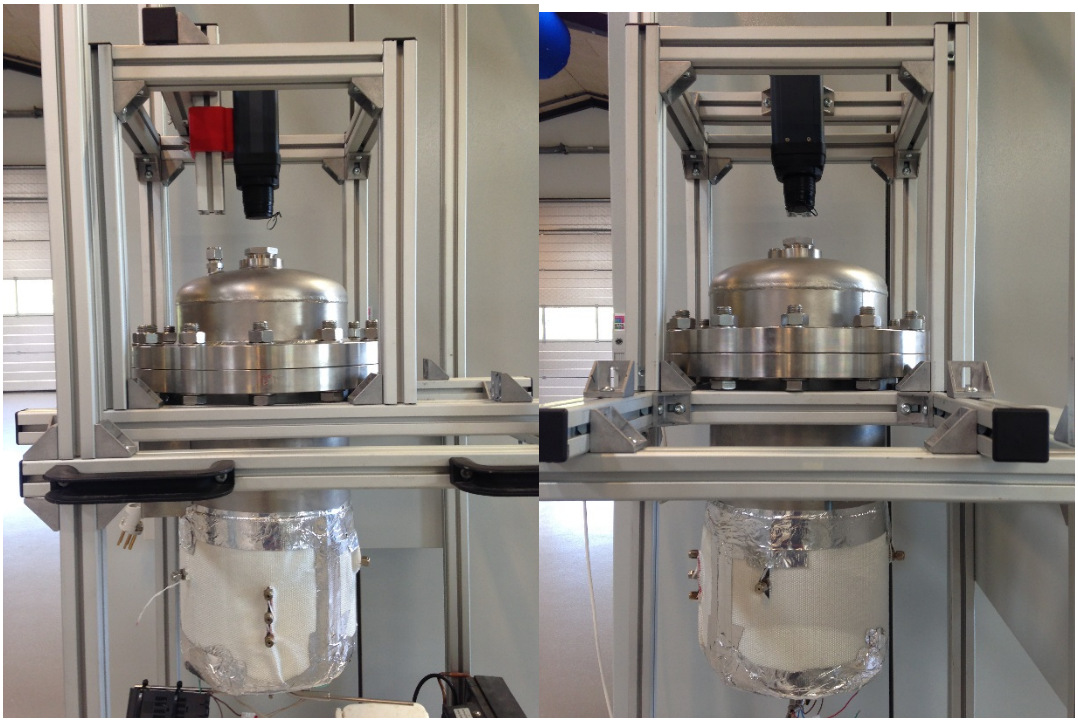

Figure 9: The methanisation reactor, with the thermographic camera mounted on top. In the right picture, in the bottom left part of the reactor, the three studs for gas outlet to the gas chromatograph can be seen.

Catalyst Bed

As mentioned above the reactor will be able to hold 5 L of catalysts. The catalysts will be placed on a configurable bed consisting of a stack of blades, rather similar to the design of turbine blades. When stacked upon each other and their angle position turned relative to the next plate, it will be possible to alter the gas flow through the catalyst. Due to the construction of the blades the entering gas flow will begin spinning in a toroidal pattern, with high flow rates, resulting in a highly efficient mixing of the gasses.

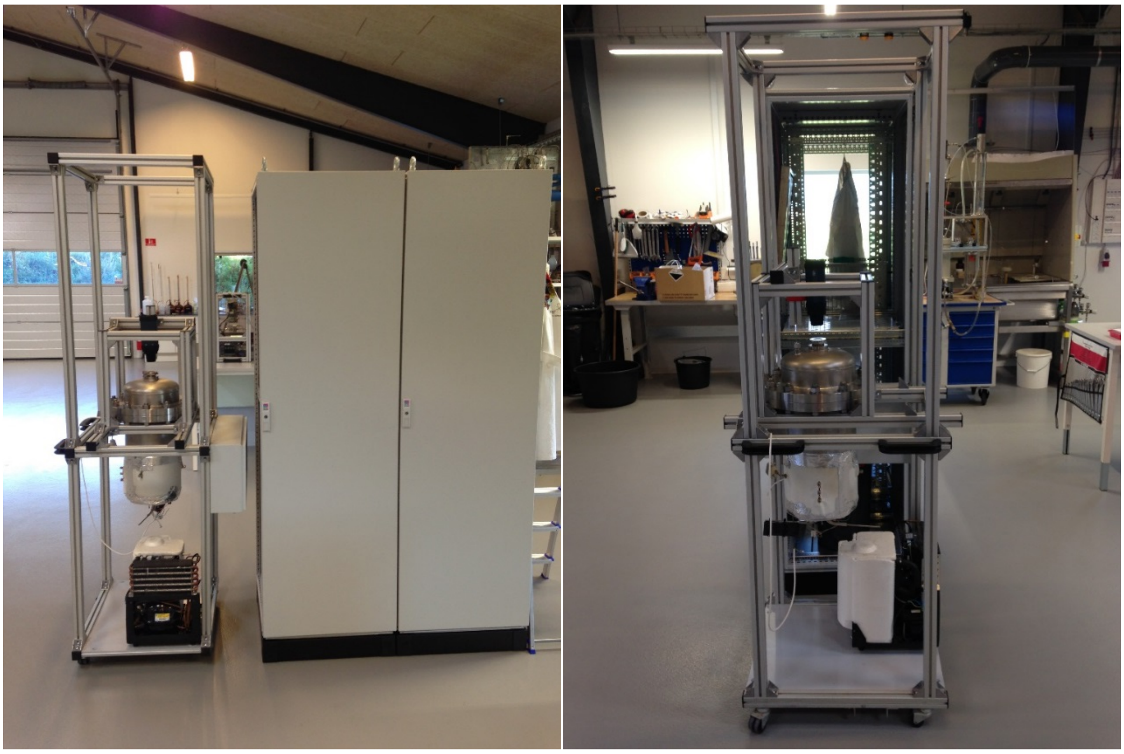

Figure 10: The reactor with the enclosing made to resemble that of the final design, i.e. the cabinets next to the enclosing. In the final design, several reactors will be in the same cabinet.

1.4.2 Control of reactor (Selection of measurement concept for methanation unit (control, monitoring and protection)

The reactor has 3 studs spaced evenly on the lower side. This makes it possible to analyze the gas composition in different layers of the catalyst bed as each stud is connected directly to the gas chromatograph. In the final version these will not be present as they are only means for benchmarking the experimental set-up and finding the optimal operation conditions. At the bottom, three circular evenly spaced studs can also be seen. These has the purpose of referencing the temperature in the top of the bed and comparing it to the observations from the thermographic camera.

Thermographic Camera

As mentioned, a thermographic camera is introduced to monitor the temperature distribution in the catalyst bed. In the heating core at the center of the reactor, there will be 4 rods; 2 cold and 2 hot. These will be able to either cool or heat the catalyst. Furthermore, these four points will provide calibration points for the thermographic camera as they will have a well-defined temperature at all times. Data from the thermographic camera will be used in conjunction with numerical simulations to predict optimum start up sequences and running conditions.

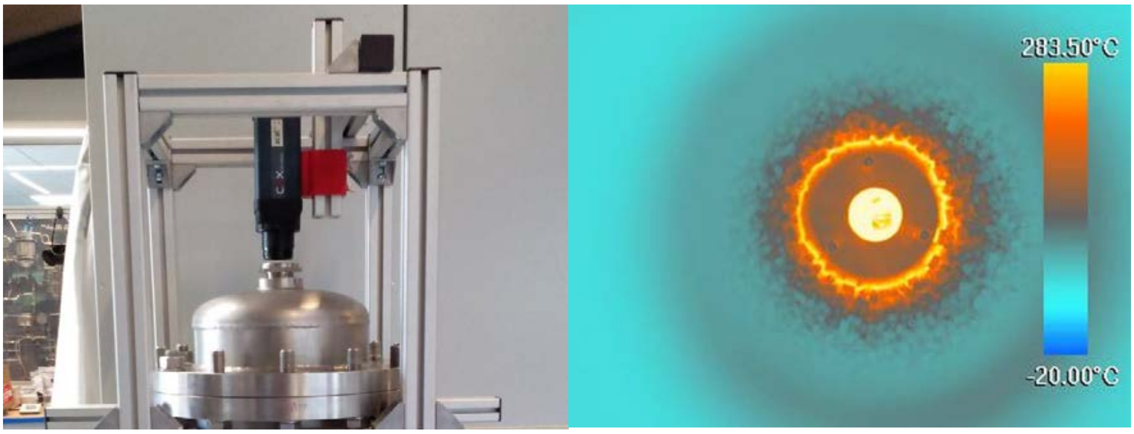

Figure 11: Left: The top of the reactor with the thermographic camera mounted. Right: The heat distribution inside the reactor as observed by the thermographic camera during heating of inert catalyst for initial testing.

1.4.3 Design review

Since delivery of the reactor, the methanation reactor setup has been completed, build and tested for 4 weeks (see figure below).

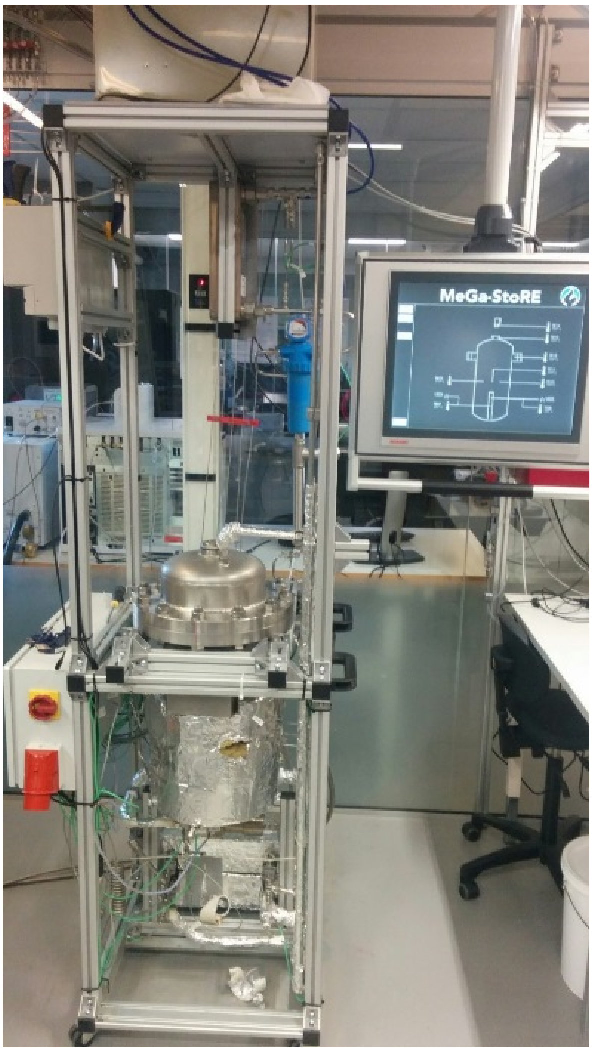

Figure 12 Methanation plant.

It has demonstrated conversion of pure CO_2 and H_2 into methane as high as 80 % by stoichiometric calculation (results exceeding the Lemvig reactor). Additionally, test with a synthetic biogas (65% CH_4 and 35% CO_2) shows conversion percentages higher than 97 % into methane. The test results are shown in the figure 13 below.

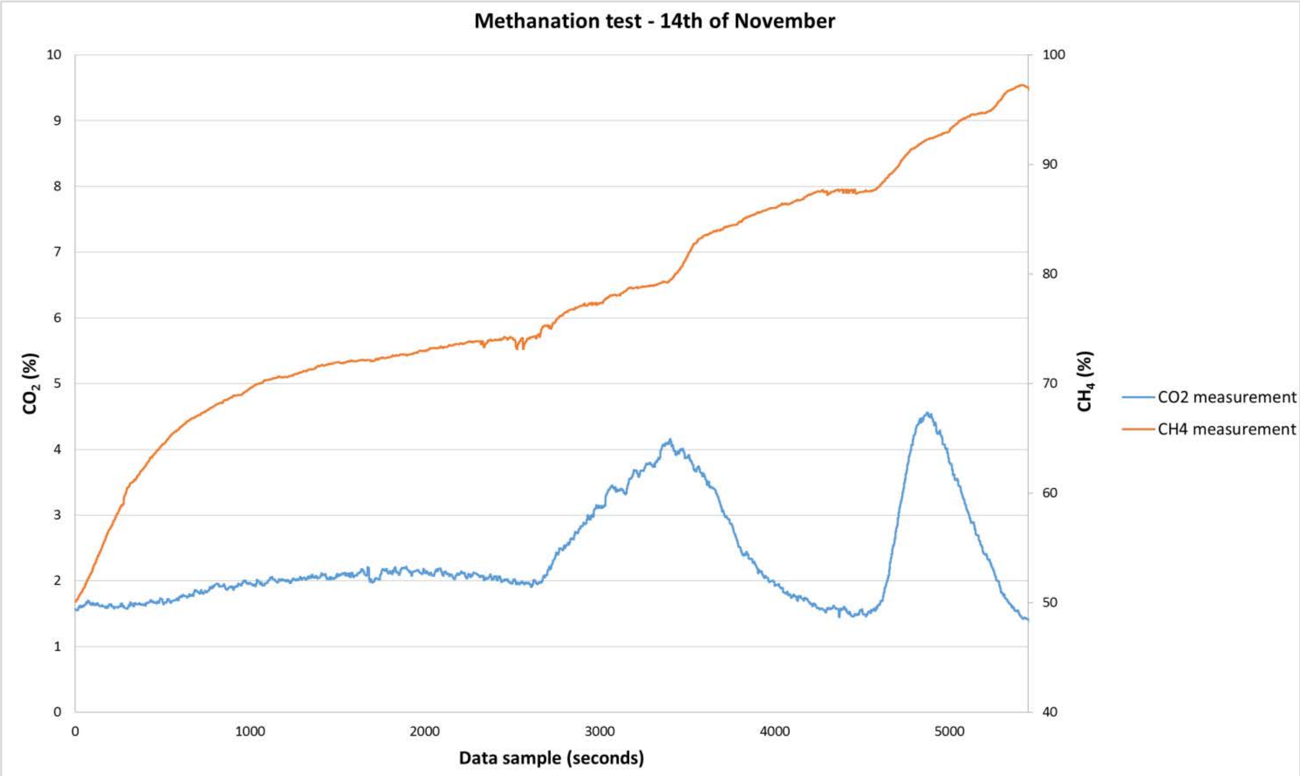

Figure 13 Methanation test with synthetic biogas consisting of 35% CO_2 and 65% CH_4. Conversion into >97% pure methane.

The following process parameters were used:

- Test time: 92 minutes
- Gas flow: 875 L/h CO_2
  1.625 L/h CH_4
  3.500 L/h H_2
- Reactor temperature: approx. 270˚C
- Reactor pressure: 7 bar
- Best set-point during test: 97,2% CH_4
  1,35% CO_2
  1,45% H_2

This test shows that the new methanisation reactor is capable of converting CO_2 into methane in one-step. The graph proves methane in the exit gas slowly increasing up to the desired level, indicated that the conversion has worked and will be working efficiently. Please also note the decrease in CO_2 content. Longer tests for further optimization of the methanisation unit will be carried out during Phase 2.
Given the primary test performed in the methanisation reactor, it is clear that the reactor is performing as expected. Further test will concentrate on heat distribution in the reactor and higher gas flows.

1.4.5 Compliance review

Construction and approval of the reactor encountered numerous challenges resulting in a delay of 3 months. This again results in a delayed initialization of the reactor. The testing of the reactor have started, and due to the delay, it has not been possible to finalize the testing concerning longevity and stability within the period of phase 1.

This could eventually lead to a small delay in the construction of the demonstration plant. Hopefully, this can be avoided, as more work force has been set to work on the methanisation reactor, including another PhD student that will have focus on the reactor construction.

List of Sub Suppliers

From the start of this project, industry contact has been a continuously important part of technology development. This is specifically important, due to the system architecture, of 90-95 % standard components. Therefore, sub suppliers are a crucial part of this project.

In appendix 1, the sub suppliers, that have taken part in this project, are listed. Only the sub suppliers with whom the MeGa-StoRE project has held several meetings are listed.

Market interest

During the dialog with potential sub suppliers, a huge interest for our concept has been shown from different stakeholders at the market – primarily in Europe and Asia. The initiated commercial activities have been presenting for potential customers and partners.

With the current stage of MeGa-StoRE – although the project following the scheduled plans – it is still too early to be specific on OPEX and CAPEX. A rough, conservative price estimates for the solution is given and generally positive feedback is received on both concept and pricing.

Roughly, 1,4 m^3 hydrogen is needed to upgrade 1 m^3 biogas (remember that it is untreated biogas with CO_2). Therefore, 6,3 kWh is needed to upgrade 1 m^3.

If the current price is 0,20 DKK / kwh, the cost price of hydrogen is about 1,3 DKK. The price for raw biogas is estimated to be around 2 DKK/Nm^3 and the depreciation is approximately 0,385 DKK/Nm^3 upgraded biogas.

The finally calculations suggest a price for upgraded biogas around 3,7 DKK, not to bad considering that 1 Nm^3 gas corresponds to 1 liter of diesel fuel.

WP2 task 2.7: Electrolyzer 50 KW, downsized MW

In this WP the task is to downsize a MW unit, now known as "HyProvide™ 250" to fit the application for the MeGa-StoRE project, the reasons for downsizing are both technical and economical.

- Technical: The typical dynamic range of operation for an electrolyzer is an interval of 40-100%, if the production of hydrogen is lower than 40% it can give rise to a poor gas quality. The HyProvide™ 250 stack is built with 110 cells, each cell will produce about 0.55 Nm^3/h of hydrogen at full load. Stack length (or cell count) determines the amount of hydrogen that can be produced.
- Economical: cost saving on the electrolyzer and the installation cost.

A short description of the product.
HyProvide™ 250 is a flexible and modular cost-effective electrolyzer platform that can be installed as a single unit or several units in parallel, providing up to several MW. The standard module HyProvide™ 250 is design to produce 60 Nm^3/h hydrogen.
By the end of 2020, HyProvide™ 250 will be upgraded with a 375 kW stack and will be able to produce 90 Nm^3/h of hydrogen. This is according to the Danish strategy for electrolysis.

The strategy for the methanation platform is to create a module concept that matches the electrolyzer platform.

Year	Capacity Nm3/h	Current density mA/cm2	Stack	kWh/Nm3	kWh/kg	System LHV	System HHV	Output Pressure
2016(al)	60	400	0,85	4,492	50,0	0,6679	0,7881	30 bar
2020(al)	90	600	0,86	4,3	48,3	0,692	0,816	40 bar
2025(al)	60-240	600-1600	0,86	4,3	48,3	0,692	0,816	40 bar
2035(cl)	-960	600-1600	0,9	4,1	45,9	0,728	0,859	50 bar

Table 1 Performance platform.

Table 1 shows the performance of the platform as it is today, in green, and what is expected in the future according to the strategy, in blue. (al) = alkaline, (cl) = combolyzer, which is based on a novel alkaline PEM electrolysis cell (PEM = Polymer Electrolyte Membrane). For further information see the strategy for electrolysis 2016 at the Danish Partnership for Hydrogen and Fuel Cells http://www.hydrogennet.dk

2.7.1 Construction

In the application it is stated that the Sabatier reactor needs 12 Nm^3/h of hydrogen, but due to changes in the biogas composition and catalyst volume in the Sabatier reactor, it would be advantageous to be able to test up to a flow rate of 16 Nm^3/h of hydrogen. This can possible be achieved by bottle for storing or by increase of the electrolyzer stack.

To make the GreenHydrogen product HyProvide™ 250 suitable for the project, some modification need to be done at the electrolyzer, this process is also called downsizing. To keep this process at cheap prices and fast to produce, only two modifications will be done. The two modification is a shorter stack and a smaller Inverter.

Shorter stack

A shorter stack is needed because of the lesser amount of hydrogen that is needed to be produced by the electrolyzer.
GreenHydrogen sees the downsized stack as a prototype, therefore GreenHydrogen do only wish to run the downsized module at 75 % load continuously, due to this, HyProvide™ 250 will be downsizes to have a 91 kW stack.

Load (%)	0	25	40	50	75	100
Production H_2 $\left(\frac{nm^3}{h}\right)$	0	5,3	8,5	10,7	16	21,3
CO_2 $\left(\frac{nm^3}{h}\right)$	0	1,3	2,1	2,7	4	5,3
Biogas 60/40 $\left(\frac{nm^3}{h}\right)$	0	3,3	5,3	6,7	10	13,3

Table 2 This table shows the working range of the downsized electrolyzer - 91 KW 40 cells 68 – 96 Volts.

The table above shows the range of the downsized HyProvide™ 250. Here the range is locked to 40-100%, in green, to make sure that the stack gas quality is good enough.

Smaller Inverter

A new inverter is needed no matter the stack size, so a smaller inverter is an easy modification. HyProvide™ 250 still needs the same amount of current but power and voltage go down to 91 kW and 96 Volt on the output of the inverter.

Additional changes

To make a full operations range available to MeGa-StoRE, GreenHydrogen has decided to install a hydrogen buffer in between the HyProvide™ 250 electrolyzer and the MeGa-StoRE system. This concept is shown in Figure 14.

A hydrogen buffer in this case will be 6 large gas cylinders, that have a capacity of 50 normal liters each.

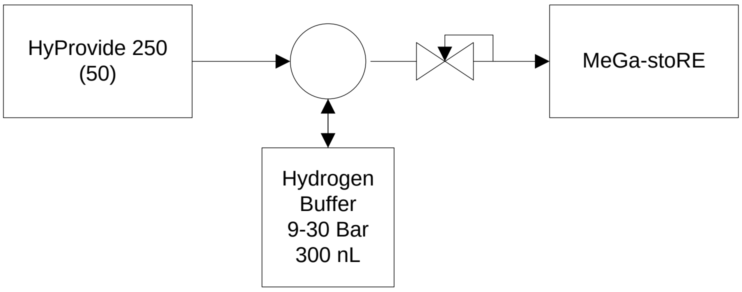

Figure 6 Concept figure of the hydrogen buffer concept.

The buffer will help to maintain a steady flow to MeGa-StoRE. It also makes it possible to test MeGa-StoRE with a low flows. The buffer also makes it possible to have a higher production flow for a short amount of time. The buffer will also create a more stable system.

The container concept has also been started to be looked at, as seen in figure 15. The look into the container concept was started in this part, because GreenHydrogen needed to know how HyProvide™ 250 would fit in a 20ft container.

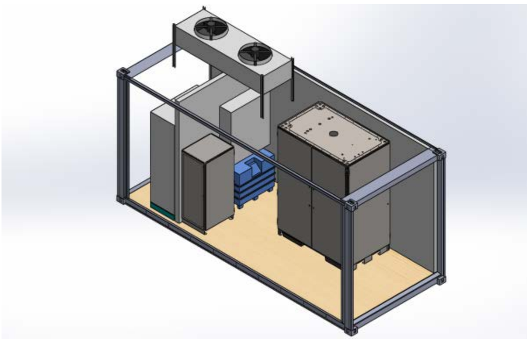

Figure 15: Concept-figure of a 20ft container concept for HyProvide™ 250 in the MeGa-StoRE project.

Figure 15 shows the container concept GH has decided to use in this project.

2.7.2 Test

Testing on the Prototype

To prepare for downsizing of HyProvide™ 250, GreenHydrogen have made some test of the system, to see what is needed to be downsized and to verify these changes.

Long-term test

Long-term test is running continuously, as part of this project and also part of daily use.

Stack	Start-up date	Time in operation	Current density	Pressure	Temperature
705 cm²	October, 2013	3350h	20 to 600 mA/cm2	0 to 30 bar	20 to 90 deg.C
3000 cm²	May, 2015	1050h	20 to 400 mA/cm2	0 to 20 bar	20 to 80 deg.C
3000 cm²	August, 2016	<1900h	20 to 400 mA/cm2	0 to 30 bar	20 to 80 deg.C

Table 3: Table of long-term test values

Table 3 shows how long each stack type has been running. All the tests have been done on the same main system.

Stability test

These tests have been done to see stability of the system and find out in which kind of running and startup operations HyProvide™ 250 can deliver hydrogen.

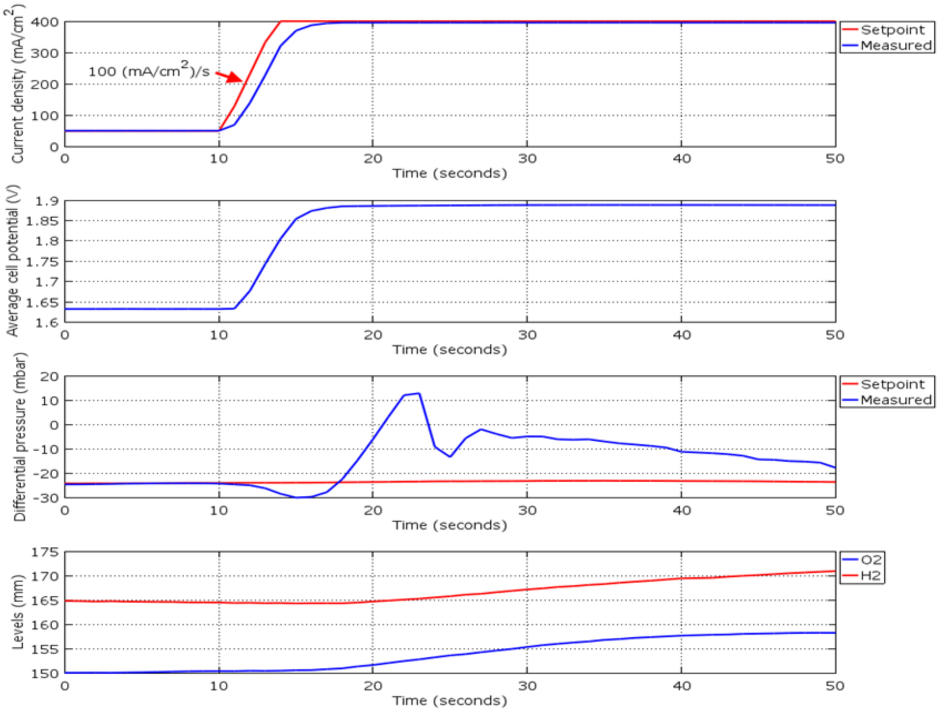

Figure 16: Ramp-up from 10% to 100% of the nominal load of 400 mA/cm2 in about 4 seconds. Temperature: 80 deg. C

Figure 16 shows that tests at running operation, where the load jumps from 10 to 100% in 4 seconds, that this systemcan be managed under this operational conditions. These tests shows that the downsized HyProvide™ 250 will be able to run within it dynamic range with slow and fast changes in load. These tests also show GreenHydrogen that HyProvide™ 250 will be able to make fast jumps from 0-100% load.

Test of dryer

The tests of dryers are done to verify if the dryer in the HyProvide™ 250 functions also with a continuously low flow of hydrogen (low load) without using too much dry gas to regenerate the dryer. This is to verify if the control system needs to be changed to take the low flow in consideration. These test have also been done at a lower pressure to see if the dryer also would be able to handle this kind of change.

The test show dryer working as it is has been observed in the HyProvide™ 250.

Jump/Purity test

The Jump and purity test is used to see if the stack gas purity is good enough under different running operations.

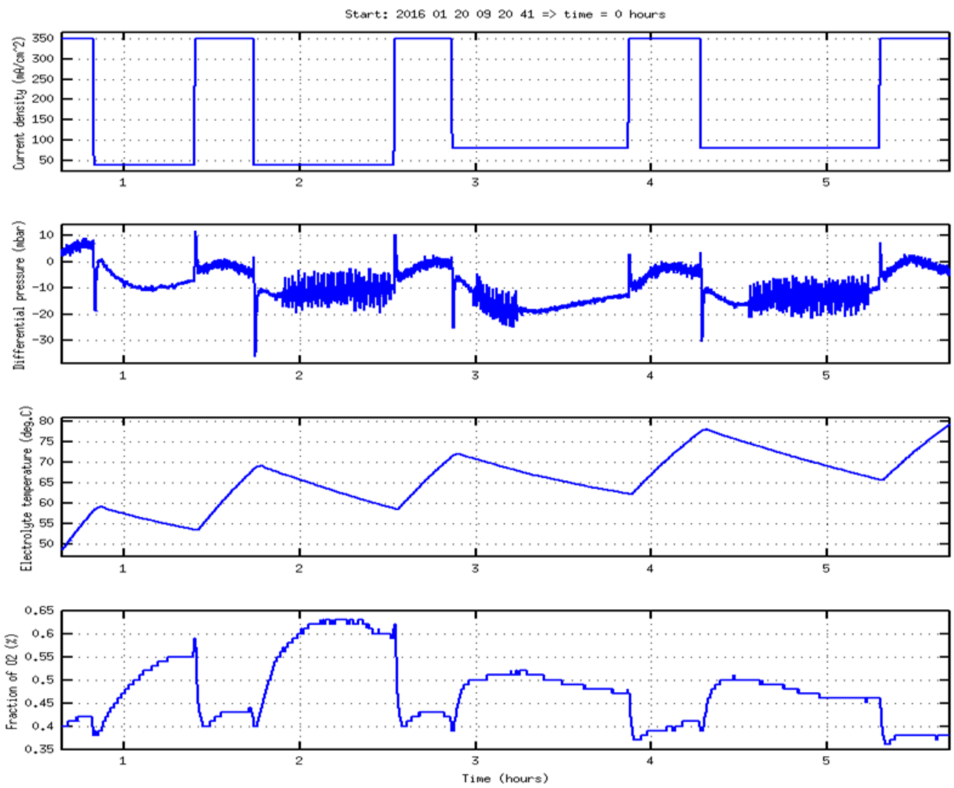

Figure 77: Purity of the produced hydrogen under varying load profile.

Figure 17 shows a test where the load was jumped from 0-100% and 10-100%.

These test shows, that to be safe it is best to keep the load over 40%, and HyProvide™ 250 can also handle jumps.

Flow test

To test how the mechanical system and the control system will handle the downsized stack. Due to the lack of available power at GH this test was done at low pressure and at low power. The test showed that the system will be more than capable to run the downsized stack at full ranges.

Lye flow test;

Test on the downsized stack have be done, to set the right flow on the shorter stack, to make sure that all cells get enough flow. Here it was found out that a smaller motor was needed for the lye pump.

Full system test

Test on the full system than will be delivered to MeGa-StoRE, cannot be done before the system is assembled, this will first be done in phase 2.

2. Project conclusion and perspective

The applicants trust that the information delivered in this report will meet the requirements for approval of Phase 1 as a kick off for Phase 2 and overall it can be concluded that the MeGa-StoRE 2 phase 1 project has been a success. Once again, it is important to stress that it is not expected that the delay during Phase 1 will cause any delay for the final report for the MeGa-StoRE 2 project. This is a result of many other project activities been handled earlier than originally planned. No additional costs then presently are expected.

Overall, the main assets of the project and their compliance with the time schedule can be summed up as:

Gas laboratory

The gas laboratory has been developed even more than what was expected at this point of time in the project. The tubing infrastructure has been founded and is ready for use.

Gas cleaning

Experiments on the TAYTAY reactor has proved that the electrocatalytic gas cleaning process works with success beyond expectations under the MeGa-StoRE 2 project.
It is expected that the continuous experimentation on the TAYTAY reactor very soon will results in enough information to draft an up-scaled version for 15 Nm^3/h biogas.

Methanisation reactor

This test shows that the new methanisation reactor is capable of converting CO_2 into methane in one-step. The graph proves methane in the exit gas increasing up to the desired level, indicated that the conversion has worked and will be working efficiently. Longer tests for further optimization of the methanisation unit will be carried out during Phase 2. Given the primary test performed in the methanisation reactor, it is clear that the reactor is performing as expected. Further test will concentrate on heat distribution in the reactor and higher gas flows.

- Product design

The final module size has been found in close collaboration with a string of sub suppliers. The product design is very mature and ahead of schedule.

- Electrolyzer

The final design of the prototype has been tested and the design of the downsized electrolyzer has been finalized. In the next face the focus will be on getting the different approvals for the electrolyzer and the construction of the electrolyzer that is going to be installed at NGF

The MeGa-StoRE 2 - phase 2 - will benefit from the results of this project, especially knowledge acquired and the sub supplier system constructed.

Although the technology is still approximately two years from been a product ready to be commercialised, a very keen interest from potential customers, as technology- and industry partners, have been observed. Probably the TayTay process will be commercialized of partners before the MeGa-StoRE 2 project finish – but that will not seize resources from the MeGa-StoRE 2 project. Given the project can deliver on the promises it holds – on capacity, size and pricing - GreenHydrogen expect to utilize the project results commercially.

One important step will be to establish a fully functional, internal demo solution in Q2, 2017, where customers can get acquainted with the technology and all components of the entire methanation value chain (electrolyzer, gas-purifying unit and methanation reactor) in a fully functional, live demo-system. This is specifically important, as our concept represents a completely different solution/a change in paradigm when compared to currently available methanation solutions from large industry players like e.g. MAN, Linde and Topsøe.

For the most effective market access, the plan is to pursue a partner strategy aligning the strategy for electrolyzer practiced by GreenHydrogen. Dialogs have been initiated with a number of potential partners – primarily engineering companies and system integrators focusing on renewable energy projects, energy companies and industry partners. However, engagement with these is only made if they demonstrate an understanding and appreciation of the critical timing, the status and challenges of the technology and of the business case. Additionally, we only concentrates on projects in nearby markets for the moment.

An overall strategy for the MeGa-StoRE should be delivery as turnkey solution through industry partners and system integrators to avoid any obstacles with regards to requirements for upscaling the business. Countries like Denmark and Germany have ambitious plans for methanation and based on information from a potential partner in Germany, the potential market for MeGa-StoRE in Germany is estimated to be +2000 biogas plants. Our modular concept appeals to smaller biogas plants (lower initial investment) and the concept will distinguish clearly from competitors like Linde, MAN and Topsøe, who all focus on large, heavy-duty methanation plants.

Milestones

M 1.1 Product specification approved

The objectives of WP1 was to investigate different possibilities for upscaling from the 1 Nm^3/h size of the MeGa-StoRE proof of concept design, to a 8,5 Nm^3/h concept matching a downscaled 250 kW to a 50 kW electrolyzer module.
In order to do so, a new methanation reactor was designed to process approx. 10 Nm^3/h biogas. Unfortunately, the construction of the new methanation reactor was delayed due to an extensive approval process.

The new reactor has been tested over the recent months. However, as stated in the project application according to deliverable D.1.4 "Design considerations methanation unit researched" the objective was to consider different design considerations for the methanation reactor. This objective now has been fulfilled with the new up scaled and optimized reactor.

Different cleaning methods have been investigated and the module size will match the methanation reactor.
In the road map, it was proposed that the reactor size should increase over time. With the module-based design that is being investigated, however, the increase in plant size can be achieved much faster than the road map indicates. With over 90 % standard components and a modular based system, scalability is in focus.

M 1.2 System architecture approved

The overall modular system architecture has been under continuously development during the project. It is now agreed upon that the philosophy of the project should resemble that of a server park, not only in appearance, but also in configuration. Instead of having a single, large, reactor this project aims to have several, smaller, reactors. More specific, the system architecture is based on containers installed with rack cabinets, where each rack represents a module (cleaning, methanation, compressor, etc.). See figure 18 below.

Figure 18 Container solution with rack cabinets installed.

This way, if a single module fails, the overall system can continue with no down time.

Furthermore, the module that has failed is designed as to make it possible to *hot swap* with a new module. From this, another advantage is that the failed module can return to the workshop and be fixed, avoiding *in situ* repair.

This modular system architecture has many advantages over a large-scale reactor plant. It is movable, it can be adapted over time to meet biomass resources and it can be scaled to meet financial position of the buyer. Additionally, the aim is to have 90-95% standard components meaning that delivery time for each modular plant is fully optimized.

In general, this system architecture approach is a new way of designing energy plants. It has received high recognizing in the industry and among system planners at Energinet.dk. They can all see the idea behind the design and the modular approach.

To include some calculations, roughly, 1,4 m^3 hydrogen is needed to upgrade 1 m^3 biogas (remember that it is untreated biogas with CO_2). Therefore, 6,3 kWh is needed to upgrade 1 m^3. If the current price is 0,20 DKK / kWh, the cost price of hydrogen is about 1,3 DKK. The price for raw biogas is estimated to be around 2 DKK/Nm^3 and the depreciation is approximately 0,385 DKK/Nm^3 upgraded biogas.
The finally calculations suggest a price for upgraded biogas around 3,7 DKK, which is an acceptable price for green fuel considering that 1 Nm^3 gas corresponds to 1 liter of diesel fuel. It can furthermore be pointed out that the gas is 100 % free from impurities and suitable for high valuable product in the petrochemical industry.

M 1.3 Compliance review of concept approved

The safety standards for the MeGa-StoRE concept has been a central part of the project. All pressure bearing equipment must have a PED approval. Since many of the components used in the project is supplied from sub suppliers, approval has already been made. However, in the case of the reactor, a comprehensive approval process by Inspecta was necessary.
The overall system architecture must meet a CE approval.
It is not possible to get a CE approval before all equipment is assembled. It is important to stress, that PED approval for each part has to be fulfilled before a CE can be approved. Therefore, the CE approval for the system can first be carried out when the equipment is clear for delivering at Nature Energy. It is also important to make clear, that CE is easy to get, when all PED approvals are obtained. With respect to the methanisation part, we are in close dialog with Inspector, which makes the PED and finally the CE. It should be mentioned that Nature

Energy do not accept any equipment, which do not have PED approvals and finally CE approvals. This applies to both the hydrogen and the methanisation equipment, which in this case is two different pressure-bearing systems. For the moment, the methanisation equipment under design and construction has all PED approvals. It should also be mentioned that phase 1 is about design considerations and not complete system build – so principally we are in front of the scheduled plan.

3. Dissemination of results

It can be noticed that on the 16th of November, 50 people were visiting the research facilities in Horsens to witness state of the art technology development and progress. It was a conference arranged by the MeGa-StoRE team together with Ingeniørforeningen IDA. Furthermore, professor Per Møller has made lectures at least 3 times - in both Copenhagen and Århus for IDA, where more than 200 persons has participated.
December this year Per Møller was invited speaker to University of Kuwait, where he was lecturing about green energy and the Danish MeGa-StoRE concept.
The former project coordinator Lars Yde has furthermore made numerous of talks and articles in nonscientific journals about MeGa-StoRE, and has used about 6-8 months full time in MeGa-StoRE 2 - part 1 joining meetings in the area of sustainable ideas, and it is hard to find people in Denmark, which do not know MeGa-StoRE. A simple search at Google confirm the large dissemination activity. There is furthermore established a homepage in English http://www.methan.dk/ and edited a booklet about the MeGa-StoRE. ISBN 978 87 92765-30-7.

A high profile three days international conference sponsored by the Carlsberg Foundation on green methanol and methane is planned by the applicants to be held in Copenhagen this coming spring.

Appendix 1: List of sup suppliers

Rittal GmbH & Co. KG

http://www.rittal.com/dk-dk/content/da/start/

German Rittal is perhaps the most important sub supplier as they will supply both container and the server racks, in which business they are world leading. Furthermore, Rittal invited the participants in the MeGa-StoRE project to the Hannover Messe, and later to their headquarters. In the meetings with Rittal, the specifications of the racks were discussed, as especially the tolerances were of interest.

ODU GmbH & Co. KG

http://www.odu-denmark.dk/

German ODU provides connectors for both electricity, data, gases, liquids etc. In the MeGa-StoRE project, ODU provided the connectors for connecting the racks. The meetings involved, as with Rittal, discussing tolerances, and both sub suppliers participated in the Hannover Messe where a large meeting with both sub suppliers were held, and the discussion was later continued at the Rittal headquarters.

Christian Bürkert GmbH & Co. KG

https://www.burkert.dk/da/

The German company Bückert provides solutions for flow of both gas and liquids. Flow controllers, pressure sensors, security measures etc. can all be combined to a single component and thus obviate a large amount of tubing. Besides meetings in Horsens, Bückert was further contacted at the Hannover Messe.

OEM Automatic Klitsø A/S

http://www.oemklitso.dk/

In MeGa-StoRE 1, the flow controllers were the entire brand Brooks, supplied by OEM. This meant that all of the flow controllers in MeGa-StoRE 2 phase 1 that were reused from the MeGa-StoRE 1 were of this brand, and the contact with OEM were mostly of a product support kind as different flow controllers failed during the project. Optimum working conditions and limitations were also discussed.

Vögtlin Instruments AG

https://www.voegtlin.com/

Several meetings were held with Vögtlin, and it was determined that their flow controllers were a better fit than the Brooks flow controllers for the MeGa-StoRE project. The overall working principle are the same, however, the Vögtlin flow controllers allow for more easy programming and have a modular construction. Furthermore, the Vögtlin flow controllers are cheaper.

G.A. RUSTFRI A/S

http://www.ga-rustfri.dk/

Danish GA Rustfri was originally proposed as the manufacturer of the methane reactor. Upon inspection of the drawings to the reactor, however, it was found that GA Rustfri did not have certificates to all of the required manufacturing processes.

RUTEK A/S

http://www.rutek.dk/da/

Danish Rutek manufactured the methane reactor on behalf of GA Rustfri. Further manufacturing of reactors is expected to be performed by Rutek.

ALL-LOK ApS

http://www.all-lok.dk/

Danish ALL-LOK has been a part of MeGa-StoRE since the early days and provides all the fitting equipment required. Concerning the construction of the methane reactor plant, ALL-LOK has furthermore contributed with a network within the fitting industry. The meetings with ALL-LOK has mostly been to discuss the limitations of the simple couplings of gas tubes that ALL-LOK can provide when compared to the connectors provided by ODU.

sera GmbH

http://www.sera-web.com/n

German Sera will provide the compressors. Sera has the distinct advantage in their compressor assortment, that they are able to supply compressors in the module size of the MeGa-StoRE 2 project. These compressors are based on their standard components and thus are very much in line with the philosophy of the project.

Rayotek Scientific Inc.

https://rayotek.com/

Rayotek is a high-tech manufacturer of sight windows for all applications, including the space industry. In this project, Rayotek provided the sight window for the reactor that allows the infrared light to penetrate and be measured by the thermographic camera for control of the temperature in the reactor.

Strandmøllen A/S

http://www.strandmollen.dk/

Danish Strandmøllen provides the gasses used in the experimental set-ups. In the meetings, however, handling of the gas and possible gas mixtures have been discussed. Strandmøllen have had experience with handling, especially CO_2, at elevated pressures, i.e. by heating, and shared these experiences.