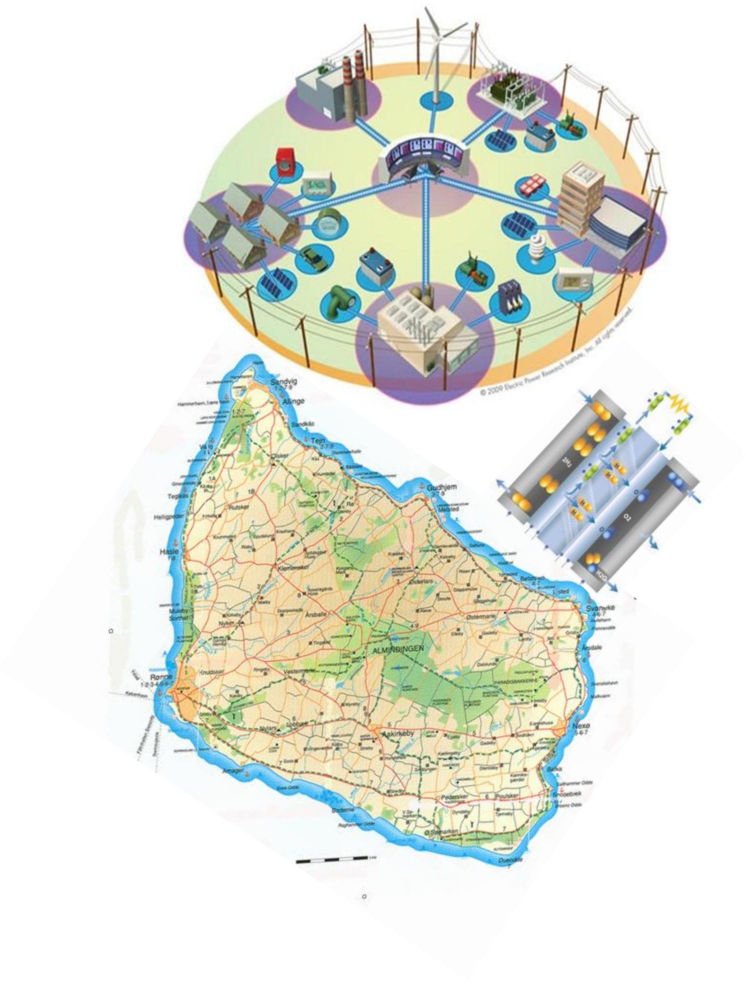
SmartGrid connected fuel cell based CHP on the island of Bornholm

#10644 **SmartGrid FCCHP on Bornholm**

Dantherm Power A/S and Centre for Electric Power and Energy (CEE) /DTU

Final report



Dantherm Power A/S

Hobro, 8. Maj 2013

Index - Final Report

1. Final report

1.1 Project details

Project title	*SmartGrid connected fuel cell based CHP on the island of Bornholm* SmartGrid FCCHP on Bornholm
Project identification	Energinet.dk project no. 10644
Name of the programme which has funded the project (ForskVE, ForskNG or ForskEL)	ForskEL
Name and address of the enterprises/institution responsible for the project	Dantherm Power A/S Majsmarken 1, 9500 Hobro
CVR (central business register)	3080 4996
Date for submission	8 maj 2013

1.2 Executive summary

A consortium around Energinet.dk is starting a project on establishing the island of Bornholm as a test side for SmartGrid with distributed power as an important element. The present project focus is to include fuel cell based combined heat and power units as active elements for sourcing and sinking power to and from the SmartGrid.

The first step is a pre-project to analyze the need and opportunity as well as the technical and economical possibilities for realizing fuel cell based CHP systems in alignment with the EcoGrid.EU project as described in www.eu-EcoGrid.net.

In this pre-project we will prepare for at a next phase that will address the issue of balancing the grid by compensating for the fluctuating renewable energy resource from wind and solar in the in the frame of the SmartGrid concept. The plan is to introduce controllable fuel cell based combined heat and power, CHP units of different sizes that will introduce an additional element which will increase the value of the EcoGrid.EU project. The project will help improving the grid stability and the integration of more variable renewable energy.

Further, the project aims at identifying potential locations for deploying FCCHP in the Bornholm power system taking into account the capacity and local constraints of the power grid. Different fuel options like hydrogen made by electrolysis, propane and biogas will be included in the investigations.

Potential partners on Bornholm for hosting the units will be identified and co-financing pursued. This project will explore the possibility to development and demonstration of fuel cell based CHP including micro scale units and large scale units used to balance fluctuating renewable energy sources by sinking, storing and sourcing electrical power in a larger SmartGrid context. The plan for this pre-project is to set up a consortium, secure co-financing from the companies and institutions involved, and applying for PSO or alternative funding for the next phase.

The results from this pre-project show that it is technically possible to integrate FCCHP units in a SmartGrid project on the island of Bornholm. The FCCHP potential for balancing fluctuating energy sources by sinking, storing and sourcing electricity is definitely present – at least for the larger units which include electrolysis.

The best place to host such units will be on the eastern side of the island, where the need to balance the grid is the strongest. A more specific location could be "Nexø Halmvarmeværk" where it would be possible to sell the heat to the district heating grid". Dantherm Power will be able to provide large FCCHP systems from 20 kW to 6 MW (in multiple of 5, 50 or 333 kW), and has excellent references in the area.

For the smaller CHP units (app. 1 kW electric) which within the timeframe of the Ecogrid.eu project has to be fuelled by LPG (liquid propane gas), technical changes has to be made to the CHP products in order to provide the necessary services to the grid operators. Among these proposed changes are extra electric capacity and a move away from the current heat load operation mode. Both issues are dealt with by CEE/DTU and Dantherm Power outside this project.

After having had contact with a number of potential partners, and having tried to scale the project down to the current economic reality, we unfortunately had to skip the materialization of our plans. This was partly because it wasn't possible to find the necessary co-financing and partly because a vital player in a materialized project (Østkraft) couldn't allocate the necessary resources to the project.

It is off course disappointing to the partners that the consortium couldn't make a SmartGrid project with Fuel Cells materialize on Bornholm. However this project has definitely contributed with valuable learning, and the efforts being put into the research at CEE/DTU and with the increased focus at Dantherm Power on developing products for inclusion in SmartGrids, we are certain that we will see both larger FCCHP's and micro CHP's in future SmartGrid demonstrations also in areas without natural gas.

1.3 Project results

In this paragraph the work done in the individual work packages will be presented:

1.3.1 WP 1

Conceptual study on needs, possibilities and opportunities related to the Bornholm grid and interrelation with alternative resources:

A short introduction to Bornholm

The distribution system of Bornholm, as shown in Fig.1, is operated by the local distribution system operator (DSO) ØSTKRAFT and serves the need of electricity for more than 28,000 customers at Bornholm. With respect to area, electricity demand and population, Bornholm corresponds to approx. 1% of Denmark. The wind power penetration in 2007 was more than 30%, and the thermal load is mainly covered by district heating. The Bornholm power system today, represents a unique facility for experiments with new SmartGrids technologies, and it is part of the experimental platform for power and energy, PowerLabDK [1]. On the customer side the drive to install FCCHP is to be self-sufficient with heat and power in a cost effective manner. The primary drive for the local DSO is currently to be able to adapt, balance and exploit and ever increasing number of wind turbines.

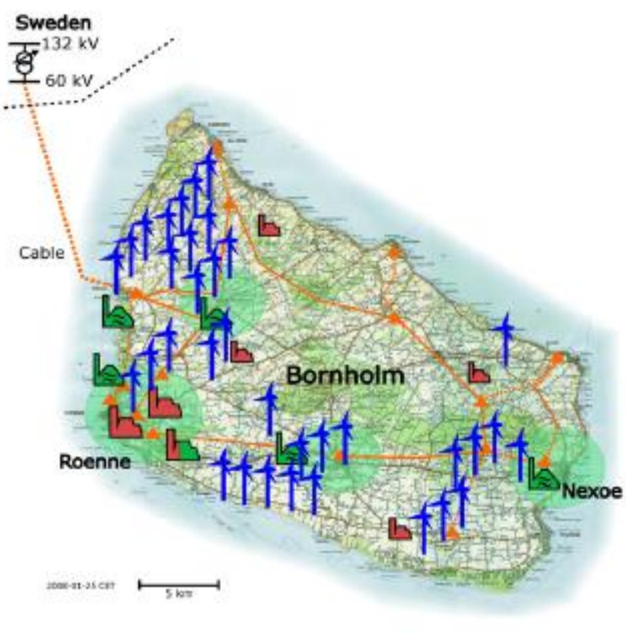


Fig. 1 The island of Bornholm with major generation units, wind turbines and 60 kV grid (Total area is 588.5 km²).

Interconnection of small-scale FCCHP for single families

Small-scale FCCHP in the range of 900 Wel to 2000 Wel is intended for use in residential and light industry environment. In Demark, the interconnection of small-

scale FCCHP must comply with the Technical Regulation 3.2.1 [2] maintained by the Danish TSO Energinet.dk.
To simulate the interconnection of small-scale FCCHP in the LV grid of Bornholm, a study case was performed using DIgSILENT PowerFactory. This study case simulates a typical Danish 400V LV feeder in rural area, as illustrated in Fig. 2, with various penetration levels of uncoordinated small-scale FCCHPs (1kWel). The grid impacts on voltage variations, transformer loading, power losses etc. are quantified via the hourly based annual power flow analysis. Detailed information of this study is given in [3].

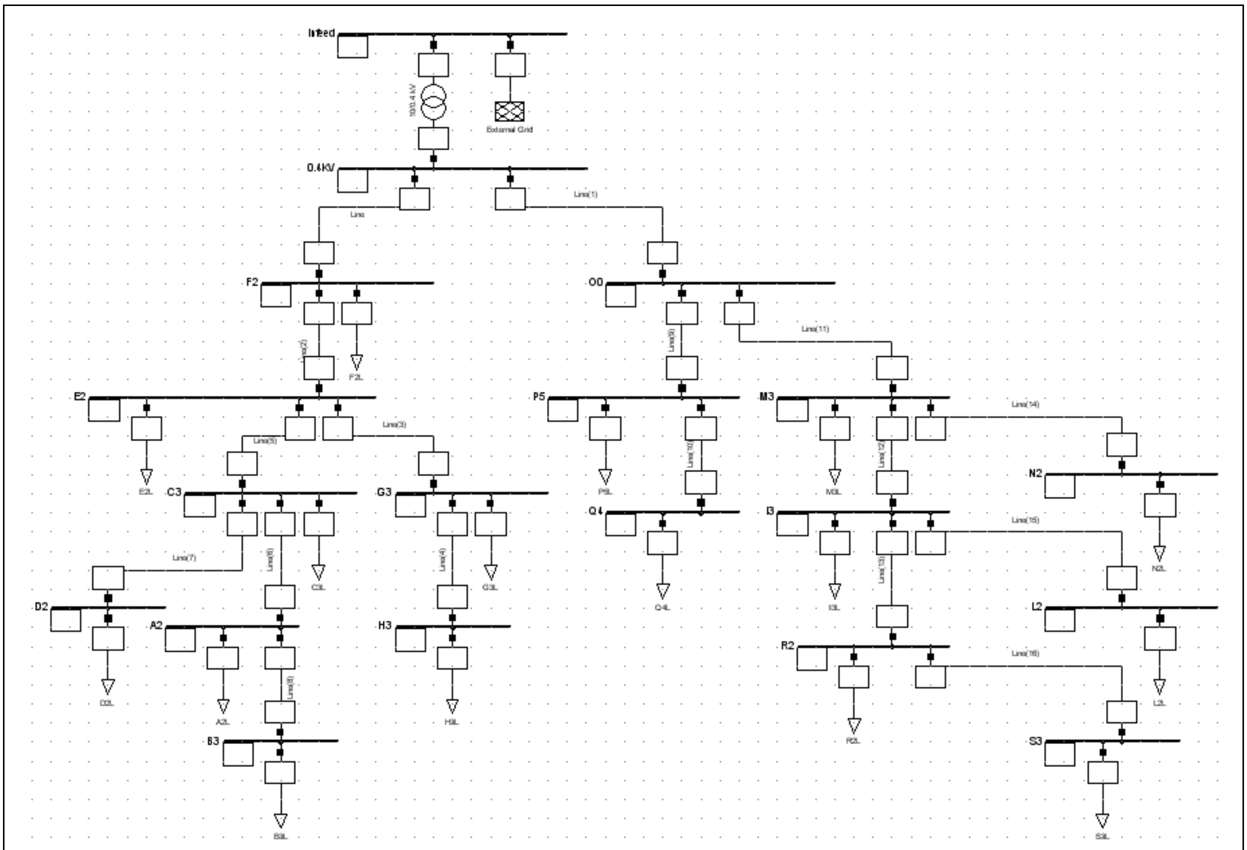


Fig. 2 Topology of a residential LV network for rural area in Denmark.

In addition to balance the wind power, the FC powered micro CHPs have the potential to facilitate the integration of electric vehicles (EVs). One potential technical barrier in the Danish LV grid for EV integration is that the LV transformer would be overloaded when 30% EV penetration is expected. As the FC powered micro-CHPs are also connected to the LV, it is possible that the micro-CHP integration could counteract the effects of EV integration and help improve the EV penetration. However, to realize this, the head-load operation mode for micro-CHP has to be replaced by coordinated operation strategies since the summer stops of micro-CHPs provide no contribution to the EV integration.
Key findings from the conceptual case study are presented in Table I, II and III. Following the increase of small-scale FCCHP penetration level, the transformer load-

ing decreases gradually until the penetration level reaches 50%. From 50% and above, both minimum and average values start to increase due to the increasing power injection from the small-scale FCCHP, while the maximum loading is further reduced to 43.64% with 100% penetration. The voltage magnitudes at both feeder top and feeder terminal B are slightly increased along with the penetration increase. With respect to the electricity exchange, the introduction of small-scale FCCHP tremendously reduces the electricity being imported. At 50% penetration, reverse power flow has been observed for 1579 hours within a year; while the number of hours for exporting electricity prolongs to 4679 for the 100% penetration scenario, resulting in an annual electricity export of 5.25MWh and an associated increase in grid losses.

Table 1

Pen. (%)	**Transformer Loading (%)**		
	Min.	Max.	Ave.
0	12.08	75.58	27.51
25	5.85	65.35	22.09
50	5.61	55.70	19.04
75	6.90	46.88	19.78
100	8.74	43.64	23.18

Table 2

Pen. (%)	**V_{top} (p.u.)**			**V_B (p.u.)**		
	Min.	Max.	Ave.	Min.	Max.	Ave.
0	0.9776	0.9962	0.9914	0.9684	0.9950	0.9886
25	0.9783	0.9976	0.9925	0.9719	0.9976	0.9905
50	0.9803	0.9993	0.9936	0.9745	0.9998	0.9919
75	0.9823	1.0012	0.9947	0.9785	1.0036	0.9941
100	0.9843	1.0030	0.9957	0.9812	1.0060	0.9955

Table 3

Pen. (%)	**El. Dem. (MWh)**	**El. Import (MWh)**	**Loss/Dem. (%)**	**Hours for El. Export**
0	211.20	216.84	2.67	0
25	211.20	160.88	2.39	0
50	211.20	105.24	2.26	1579
75	211.20	49.85	2.25	3852
100	211.20	-5.25	2.38	4679

This conceptual study proves the technical feasibility of having 100% penetration of small-scale FCCHP in a Danish LV feeder. However, due to the relatively low heat demand in summer time, the electrical capacity of small-scale FCCHP is not fully explored. A similar problem arises with a high number of small FCCHP units that in order to support the electricity production for the grid - need to do something with the excess heat production. Coordinated operation schemes for FCCHP e.g. balancing wind power, facilitating the integration of Electric Vehicles (EV) and providing voltage regulation [3], need to be further investigated to operate these resources in a way that not only improves the economy of FCCHP but also provides necessary services to grid operation. This kind of exploration as well as optimization is the core of the current SmartGrid work of CEE.

Interconnection of large-scale FCCHP for industrial applications

FCCHP with its electrical output ranged from 200kWel to 1MWel is considered as large-scale FCCHP for industrial applications in the distribution grid. Currently in Denmark, there is no published grid code for inverter-based units like large-scale FCCHP. However, the specialists from Energinet.DK suggest the following terms for inverter-based units above 200kWel.

a) Power quality has to be documented specific for the type/size of the inverter, normally as EN 61000-3-xx series.

b) Performance during fault has to be documented as Fault Ride Through (FRT) characteristic, which shows voltage/load characteristic during fault. The FRT characteristic will normally be available by the manufacture, but otherwise shall follow reference as given in the Figure 5 in grid code TF 3.2.6.

c) Regarding the system services, it has to be tested and documented following the reference shown in the grid code TF 3.2.3, part 9 and figure 9.

d) Choice of protection functions and settings in the PCC, which is over/under voltage and over/under frequency, shall follow grid code TF 3.2.6.

e) Documentation of the Fuel Cell technology also has to be included in the total package of documentation of the unit.

Regarding the interconnection of large-scale FCCHP, a few key findings have been listed below

- Nexø is proposed as installation site due to its anticipated increase in need of electricity and district heating.
- It is recommended that the 1MWel FCCHP (3x333kWel) is connected at 10kV level due to the increased robustness of the 10kV (compared to typical 400V grid), meaning a step-up transformer (400V/10kV) is needed. For a single FCCHP module with 333kWel, it is technically feasible to connect it to 400V via its inverter.

- The 1MWel FCCHP can be either connected to the 10kV side of the primary substation (60/10kV) of Nexø or the high voltage side of a number of 10/0.4kV substations, meaning there are many options which are all technically feasible. As such for FCCHP with 333kWel, there are multiple choices of locations.
- To fully exploit the co-generation of heat and power, the location narrows down taking into account. Integrating the FCCHP plant into the local district heating system is an important factor that affects the installation site selection. This question however needs further investigation.

1.3.2 WP 2

Investigations on fuel options:

This WP covers the potential fuels our fuel cell systems can operate on now – or in the nearby future so they can be in cooperated and used in the Ecogrid.eu project. The availability on these fuels on Bornholm will off course also be covered. Initially there will be taken a choice between use of CHP systems build on the technologies SOFC and PEM in the actual demonstration project.

SOFC or PEM technology for the SmartGrid demonstration?

Considerations about readiness/matureness of the fuel cell technologies for SmartDrid demonstration.

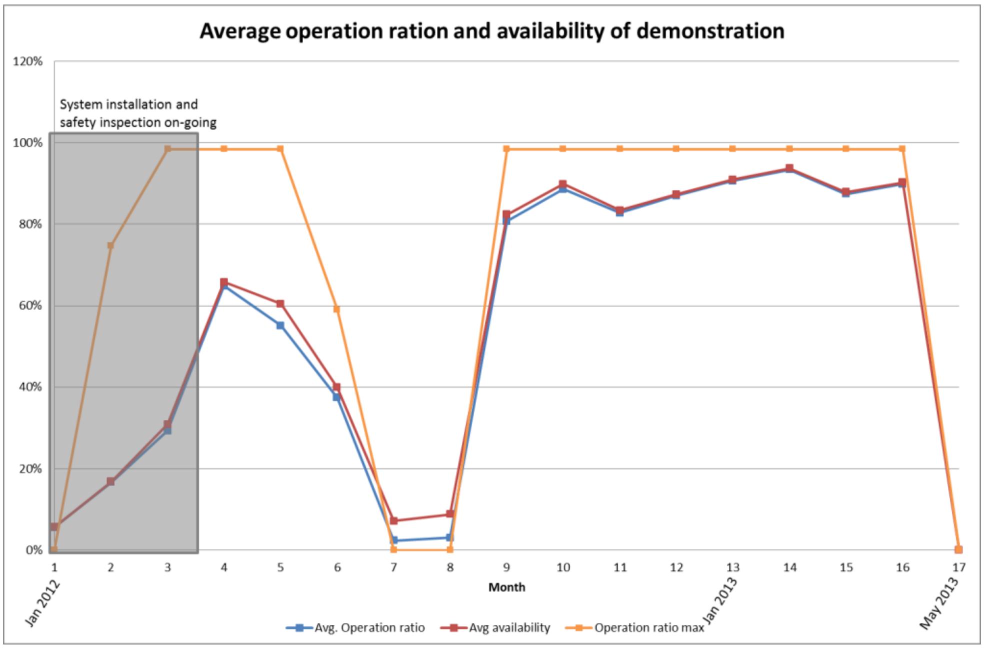
Dantherm Power's demonstration experiences with SmartGrids have mainly been concentrated around the *DONG Power Hub* VPP solution which is in operation today in the project Danish MicroCHP. Dantherm Power is one of the first manufacturers whom have tested the OPC-UA interaction of DONG Power Hub which utilizes no additional hardware as long as the systems have internet connection.

The most attractive economic possibility for integrating FCCHP's in a VVP is delivering regulating power to the grid. Winning a bid for regulating power, gives a ready to regulate fee from the TCO. Requirements for delivering electrical power as a bid in Denmark requires 30s or 15 min capability depending on the type of regulation which is offered. This in turn sets certain requirements to system dynamics.

Fuel cell systems utilizing a reformer will have significant start-up and shutdown time. On our current systems the startup time is in excess of 1 hour. Furthermore the systems require electrical power during startup - putting extra stress on the grid they are required to support. This means that the most promising operating strategy will be to use systems already in operation for regulating power. This in turn requires excess capacity of the systems that can be accessed on demand. The system will not operate fully controlled by heat demand as typically serving only the needs of a single family home needs demand.

The cost (extra capital cost) of the excess power capacity depends on the technology maturity. The technology in Dantherm Power's portfolio that has the highest level of maturity is the LTPEM technology. Latest cost price of system is from the Danish µCHP demonstration with 344.000kr/kW for SOFC and 209.000kr/kW for LTPEM. The cost is expected to drop significantly when the market increase. It is expected that a LTPEM µCHP will drop to less than 70.000kr/kW when production volume increase to 10.000 units pr. year.
Availability of the systems have been most thoroughly tested with the deployment of 20 LTPEM µCHP systems in the Danish µCHP program having a single unit obtaining >8.700 hours and a total of the 20 systems in excess of 125.000 hours of operation in real life in private homes. Average availability of the demonstration reached >87% during the last 5 month of operation as indicated by Figure 3. By comparison Dantherm Power have demonstrated one SOFC system for >3.700 hours at their lab facilities.

Figure 3: Average operation ration and availability of demonstration



A 2-2,5 kW core technology is under development at Dantherm Power supporting an excess power capacity of 1-1,5kW for a micro combined heat and power system in a residential household. These systems will not be using head load operation strategies, and will instead use coordinated operation strategies as suggested in WP1.

Due to the large amount of real-life experience with the LTPEM technology and the cost of excess power capacity, solutions for the Ecogrid.eu can be based on LTPEM technology.

Below can be seen the latest tested and CE marked version of our LT PEM CHP system along with some systems data:

Figure 4: Dantherm Powers LTPEM system and selected performance data:

Table 2 The DTP natural gas fuelled μCHP unit performance, LT-PEM Fuel Cell based Phase 3 unit. Measured 21/10 2011

Parameter	
Fuel	G20 (Methane)
AC 230 V output, net (W)	900
Fuel (G20) input (Nm^3/h)	0,268
Fuel input (W)	2677
Cooling water flow (kg/h)	34,5
Return temperature (℃)	25
Forward temperature (℃)	62
Thermal output (W)	1468
Condensate flow (kg/h)	0,34
Net electric efficiency (%) *)	33,6
Thermal efficiency (%) *)	54,9
Overall efficiency, net (%) *)	88,5
Flue gas temperature (°C)	34
O_2 in flue gas (%, dry basis)	9,9
NO_x (ppm, dry basis)	<2 **)
CO (ppm, dry basis)	<4 **)
UHC ***) (ppm, dry basis)	10-180

*) LCV reference
**) < Detection Limit
***) UHC:Unburned Hydro Carbons

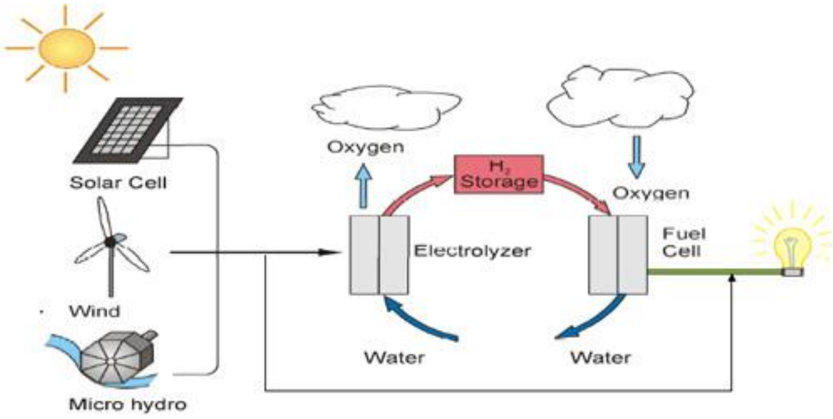
Large Hydrogen fuelled systems.

This paragraph covers Dantherm Power's ability and experiences with delivering larger CHP units range from 50 kW_{el} to 6MW_{el} to a project such as the Ecogrid.eu project. These units can be placed close to a district heating grid or a larger heat consumer if desired, where the heat produced both from the electrolysis and the Fuel Cells process can be used for heating of buildings or injection in the district heating grid.

The larger units will include an electrolysis facility for production and storage of hydrogen. The larger CHP unit systems can be used for both sinking and sourcing power in order to balance the grid, and can furthermore be used for phase regulation in weaker parts of the grid.

At Dantherm Power we already have world leading competences in supplying the fuel cell part of this system. The first major project we undertook was to supply Canadian BC Hydro and Powertech labs with a 100 kW fuel cell system for their Hydrogen Assisted Renewable Power system known as HARP. The principle behind the using the HARP system can be viewed in figure 5.

Figure 5: The overall principle behind the HARP project:



This "the hydrogen part" of the overall system works by converting electricity from a renewable source (run-of-river), in off-peak periods, into hydrogen through an electrolyzer, and subsequently into electricity through a fuel cell for power during periods of peak demand. The overall technical setup for the Fuel cell part of the HARP system and a SmartGrid project on Bornholm will be very much alike – but the controlling part of a larger system with more fluctuating electricity sources will off course be more complex.

The system was setup in the community of Bella Coola in BC, Canada in 2010. Bella Coola is one of fifty B.C. communities that are isolated from the main electricity grid. For this community micro grid their main source of power comes from the Clayton Falls run-of-the river generators. In high water demand periods diesel generators are available, but these diesel generators emit greenhouse gases, and they are not capable of storing energy for peak energy demand periods.

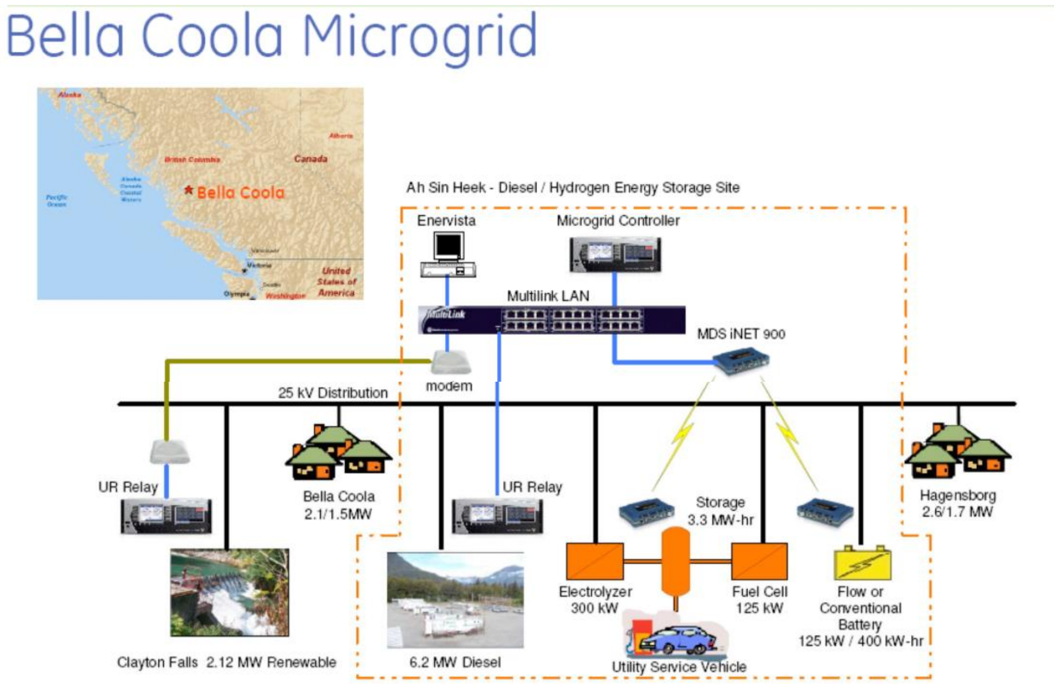
The HARP Fuel Cell container being tested at Dantherm Power in Skive.

The inside of the 100 kW container.
To the left the fuel cells and to the right the inverters.

The total system operating in Bella Coola
Including electrolyzer, fuel cells and hydrogen storage.

This system off course had to operate within the entire “micro grid” and had to be controlled in order to perform optimally with the other technologies in the grid. The entire community grid is shown in figure 6:

Figure 6: The Bella Coola Microgrid:



The General Electric Microgrid Control System functions as the "brain" of the power chain. It provides the intelligence on when to use certain power sources — the renewable hydroelectric power, the fuel cell or diesel — so that the community can find the most economical way to provide power. The SmartGrid technology wirelessly monitors the power chain and automatically responds to changes in supply and demand — ensuring energy is managed efficiently.

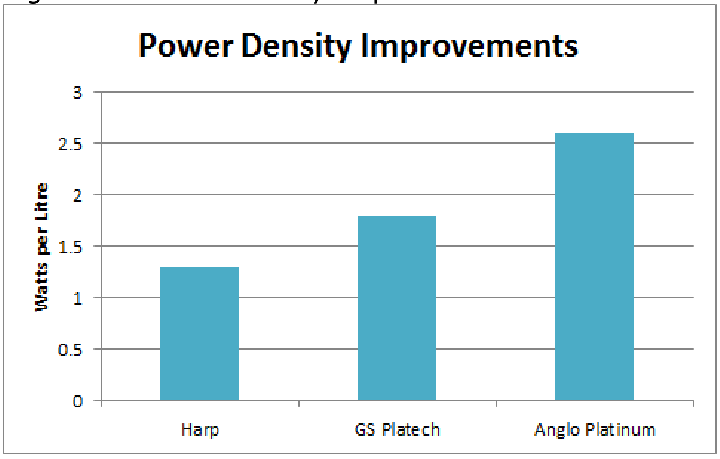
After the system having performed for a while the project responsible BC hydro concludes that the HARP system:

- Reduces Bella Coola annual diesel consumption by 200,000 Liters.
- Thereby lowering greenhouse gases emissions by 600 Tons annually.
- Hydrogen and a "SmartGrid" have the potential to reduce peaks, increase efficiency and cost effectiveness of operating micro grids.

This we at Dantherm Power believe will also be the case in a more complex "grid" such as the one on the island of Bornholm, and we have since the completion of the HARP system, in cooperation with our majority shareholder Ballard, been working a lot with cost optimizing, and increasing performance of these systems.

Figure 7 shows how far we have come with regards to power density improvements on some of the systems we have delivered since the HARP project.

Figure 7: Power Density Improvements on delivered systems since HARP



Dantherm Power is now in the process of making our second 3'rd generation multi kW solution for a Chinese Customer who will use it for producing electricity of waste industrial hydrogen. This system is built upon standard 5 kW modules and will deliver 50 kW Net AC Power. For a SmartGrid project on Bornholm we will therefore be able to deliver tested 50 kW systems or multiples of such. If larger systems are required we can deliver Ballard systems from 333 kW or multiples of such. The next tables, figures and pictures show the performance data and implementation opportunities of the Ballard systems.

The Ballard 1 MW generator

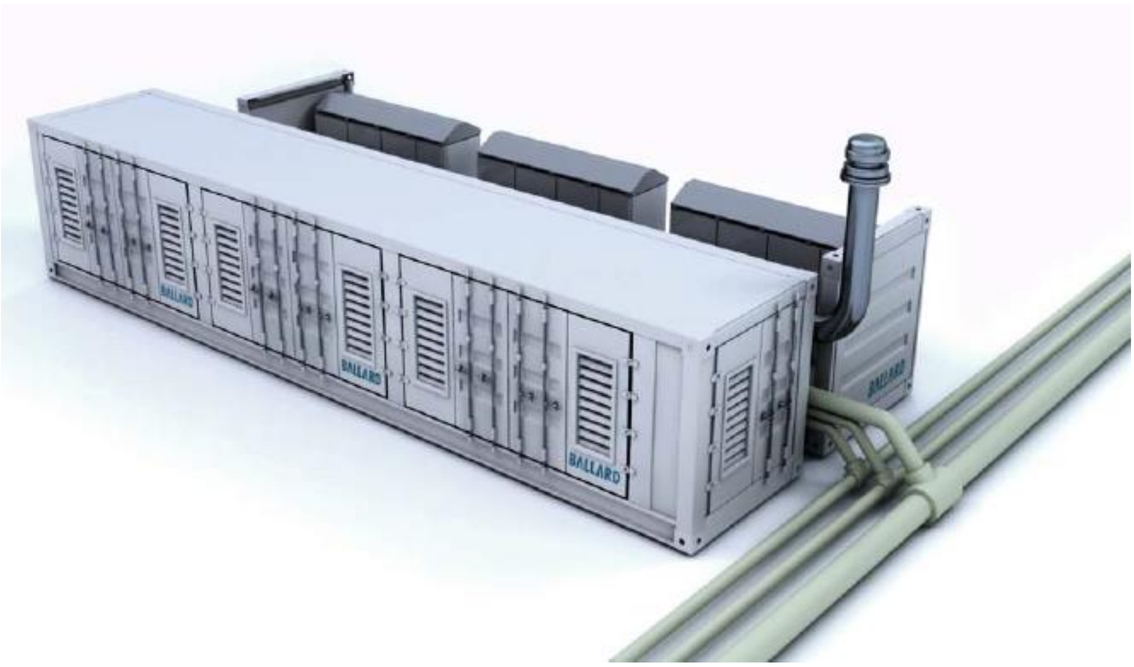
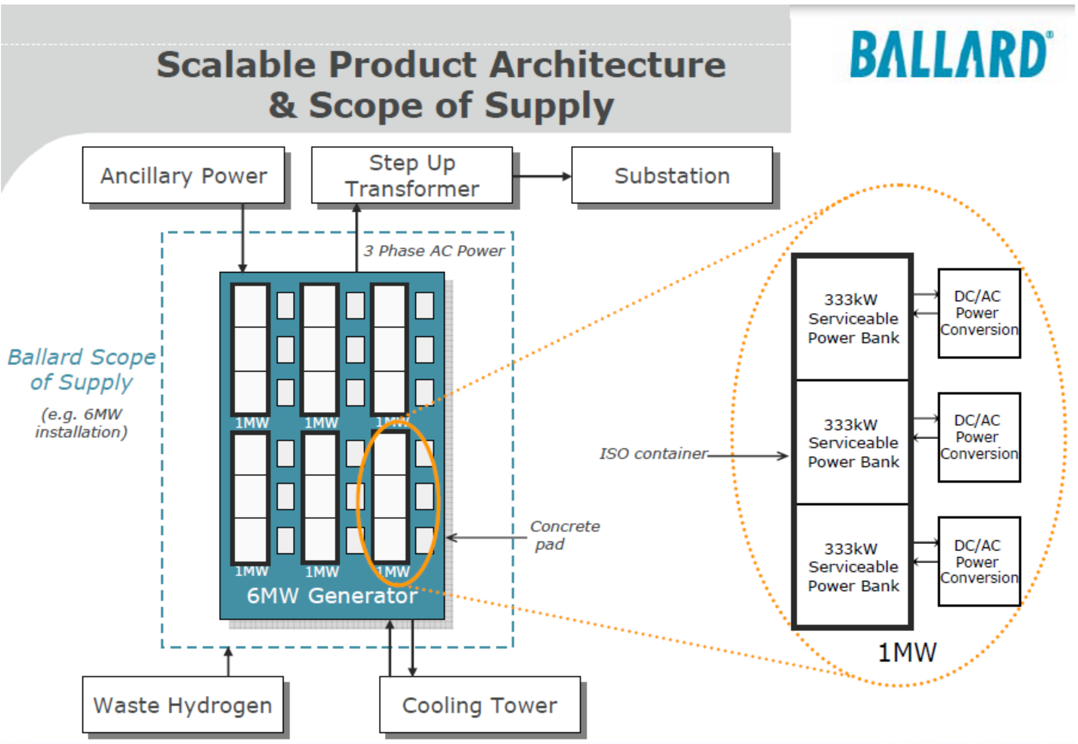


Table 4: Performance data Ballard 1 MW generator.

Type:	PEM (Proton Exchange Membrane) fuel cell generator	
Performance:	Net Power	1 MW
	Efficiency	48% (± 2%)[1]
	Output voltage	200 – 480 V AC[2]
	Output frequency	50 – 60 Hz
Physical Characterisitcs:	Height x width x length	2.9 x 2.4 x 13.7 meters
	Weight	<45,000 kg
Fuel:	Hydrogen	99.9%[3]
	Fuel consumption	65 kg/hr (730 m^3/hour)[4]
Reliability:	Availability	>80%
	Product Lifetime	>15 years
Available heat:	Output heat load	1400 kW[4]
	Stack outlet temperature	<65°C (149°F)[5]
Emissions:	Water output	< 4 LPM
	Noise	<80db @ 1 meter
	Pollutants	Zero emissions (no GHG or local air pollutants)

1. At beginning of life.
2. Step-up transformer is an optional feature.
3. Ballard can work with customer to provide customized fuel purification system.
4. Average over product lifetime.
5. System interface cooling flow rate and rejection temperature to be determined.

Figure 8: The implementation opportunities of the Ballard generator



A 6 MW plant is most likely too large and too expensive for a demonstration project on Bornholm, but the scalable product architecture is shown in order to demonstrate the possibilities lying within the technology.

The conclusion of this paragraph is that Dantherm Power in cooperation with an electrolysis supplier can deliver a fully functioning electrolysis, storage and fuel cell system in multiples of 50 or 333 kW. If smaller systems is desired these can also be delivered.

From the findings in WP1 we have learned that Nexø and the district heating company (Nexø Halmvarmeværk showed interest in being involved) could be a good site to setup a larger system – since the need for grid stabilization is present, and the need for electricity and district heating is expected to increase in the future.

Technically it is possible to connect the smaller systems (less than 333 kW) both to the 400V or 10 kW level. If we can find the funding to set up a 1MWel FCCHP it can either be connected to the 10kV side of the primary substation (60/10kV) of Nexø or to the high voltage side of a number of 10/0.4kV sub-stations.

Biogas

At Dantherm Power we are currently involved in 3 Biogas projects: Two pre-projects evolving around the use of sewage gas in fuel cells, and a regionally supported project in Southern Jutland (Sønderborg). In the latter we demonstrated and operated 2 µCHP plants running on bottled upgraded biogas in the beginning of 2012. The problem with operating on raw biogas is the number of contaminants that the fuel cells and the build in reformer is intolerant towards. The table on the next page shows the composition of biogas from 3 sewage plants in Aarhus, and the tolerance values within which our current CHP plants can operate.

Table 5: Gas composition from selected plants and tolerance values of LTPEM based systems:

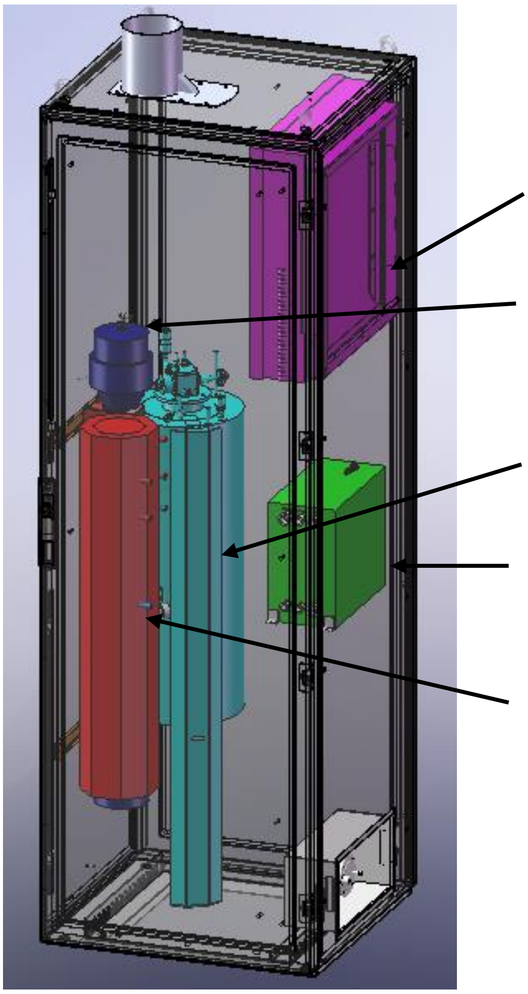
	Marselisborg RA	Marselisborg RA	Viby renseanlæg	Viby renseanlæg	Best guess from "driftsledere"	Tolerance Fuel Cell based CHP systems
Siloxaner[mg/m3]			17	24		0
Silicium[mg/m3]	1,9		6,6	9,1		0
H_2S[ppm]			510	441		<5
O_2[%]	0	0,18	0,29	0,35		<0,5
CO_2[%]	37,7	40				<5
N_2[%]	0,2	0,86				<0,6
CH_4[%]	62,1	59				>95
Toluene[mg/m3]	2,8					NA
Ethylbenzol	0,1(DL)					NA
m-Xylene+9-Xylene	0,1(DL)					NA
1,3,4 Trimethylbenzene[mg/m3]	0,2					NA
m-+p- Ethyltoluene	0,1					NA
i-propyltoluene	0,2					NA
Pinen	0,9					NA
Limonen	0,2					NA
Waterdewpoint [C]					42	<-10

As it can be seen in table 5, it is necessary to integrate a cleansing of the biogas before it can be used to fuel a PEM based CHP plant. The cleansing has to include C02, H_2S, water, siloxaner and silicium - and in some cases N_2. The exact values of the contaminants in the biogas depend of the digester used in the production of the biogas, which on some plants can vary over the year(s) depending on what is available. Currently it will be very expensive and technically difficult to do the cleansing of biogas in the individual CHP plants, so this approach has after careful consideration been abandoned - at least in the short term.

However much of the cleaning needed in order to operate the CHP plants is done when upgrading the biogas to bio-methane, as it is done in several places for example in Germany and Sweden. The upgraded gas is then used either in gas driven vehicles or for injection in the natural gas grid. Even for upgraded biogas the values of some contaminants such as nitrogen and sulphur can vary, so it is necessary to do initial testing of the composition before we can use it as a fuel.

In the Sønderborg project we used bottled upgraded biogas from Kristiansstad in Sweden. After having done initial analysis of the gas composition, Dantherm Power developed, tested and integrated sulphur absorbers in our µCHP units. The tested and demonstrated setup can be viewed in Figure 9

Figure 9: The upgraded biogas CHP system and the main components:



The reformer is intolerant towards all sulphur compounds suspended in gas or water. It is critical for the performance of the reformer that the fuel, air and water strings are free of sulphur. As a reference it shall be mentioned that the expected lifetime of the reformer running on natural gas without a desulphurizer is just 23 hours.

At Dantherm Power we have recently started testing a new version of the reformer. We hope that it in combination with better desulphurizers (with improved absorbers) and new cleansing techniques will make it possible for PEM fuel cell systems to run on pure biogas in the future.

However within the timeframe of this project we need upgraded biogas – which presently isn’t available on Bornholm. One of the only biogas plants on the island is located close to Aakirkeby - and they or any of the others are not planning to start upgrading the gas.

During the project the company BioGasol, developing a 2. Generation bio ethanol production was contacted. BioGasol, was at the start of the project, planning to establish an ethanol production based on straw on Bornholm. The planned process would deliver a waste stream of hydrogen, that could be valuable as a fuel for the CHP units. However the plans for a BioGasol project on the island were later abandoned.

However this project and other studies we are participating in only makes a biogas solution more interesting – as there clearly is a market for it in areas without natural gas or district heating. So we will definitely keep our eyes open for technological advances that can make the solution possible and economically feasible in the future.

LPG – Liquid Propane Gas

Another fuel option for the CHP systems is LPG. LPG is accessible all over the world and can be delivered on Bornholm by Primagaz. So the accessibility of the fuel is not a problem.

However the operation on LPG is somewhat more challenging than operating on natural gas. We have in cooperation with Ballard and a US based Ballard subsidiary “Material Products Inc. Maryland” since the beginning of 2010 been working on desulphurizing, reforming and testing reformers on LPG, for our CHP and Backup Power products.

The main challenge is the composition of the LPG gas - that varies a lot from country to country. In DK LPG are more than 95% propane and the rest is mainly butane – where it in Spain can be the complete opposite. This poses a major challenge for operation of the reformer and robustness to varying fuel composition handled by our control system – a challenge that is not yet completely overcome. As the LPG is liquefied in the bottle the composition of the gas coming out of the bottle will also vary from a full bottle to a nearly empty bottle.

Another challenging issue is the odorant that due to safety reasons is added to the compound. In LPG there is by Danish law required 2,2 times more oderant than in natural gas – and since the oderant contain sulphur it has to be removed before it reaches the reformer. The allowed total sulphur is a magnitude of 1,7 larger compared to Danish natural gas.

The procedure of removing the sulphur is more complex due to the longer hydrocarbon chains in propane and butane as well as the higher amount of odorant. Furthermore two major types of odorants exist: THT or mercaptans. THT is used in Denmark.

We are currently testing the complete desulphurizing and reforming setups in our labs and we hope to have the complete LPG CHP systems ready for the final tests in the summer of 2013.

1.3.3 WP 3

Investigations on SmartGrid integration and adaption of the ICT platform, and deployment of limited monitoring devices in selected locations:

In order to finally achieve Plug-n-Play functionality across all vendors, types and manufacturing, communication infrastructure and ICT platforms deployed at Bornholm we will aim at the future "Final solution" which is recommended by Energinet.dk. FCCHP will and should follow the recommendations [6].

Regarding FCCHP and communication work was focused on how to operate and optimize the operation of a 1.2kWel unit in conjunction with a hot water buffer tank. The communication was set up in a simple manner with only OFF and ON settings as the present model does not encourage doing manual or remote control of ramp up and down time. The work on optimizing the operation is on-going as of 2013, as well as parallel work with the communication platform based on the 61850 is carried out, both for the FCCHP as well as internal combustion engine based CHP's. Currently, this platform is developed for EV's on a principle of a central or aggregated control. Further, this platform within the realm of EV's is being aligned with the standard for communication between EV and public charging spots, IEC/ISO 15118. Recent work with CHP's has been initiated where also the resources in a 61850 compliant manner will be public available in the cloud.

In a related project [7] models were created in DigSILENT Power Factory (PF) and MATLAB with access through Java software. Further, a real time digital simulation (RTDS) model of Bornholm was created for the 60kV network. Both a generic model as well as a lump model was generated. This work deals with coordinated frequency control for islanding operation of distributed generation (DG) which in its nature is very relevant to a distributed deployment of FCCHP's although the voltage level in this case does not match. The objective of the model was to demonstrate balancing capability through coordinated frequency response on wind and solar power generated fluctuations. Different solutions requiring automatic generation control (AGC) were presented with DG's and in particular with battery energy storage. Solutions for the primary and secondary control were investigated, however, the stringent requirements to response time and in general to timing was not addressed, neither was the communications. In the case of deploying distributed small scale FCCHP the timing should not be critical as small scale FCCHP is not anticipated to participate in the fast response/reserve services (with the current electric capacity and operation strategy). However, it may be relevant for a larger FCCHP connected at either 10kV or 60kV to have sufficient contingency to handle fast responses through a dedicated and standardized communication.

1.3.4 WP 4

Identification of additional partners for the next phase:

From the previous WP's we have concluded that the most optimal site for the big FC unit and electrolyzer is on the eastern part of the island. Nexø Halmvarmeværk could be a very good choice of site as it is technically unproblematic to connect the FCCHP, and it is also a possibility to sell the produced heat to the district heating grid.

Within the timeframe of the Ecogrid.eu project Dantherm Power can only deliver PEM CHP systems running on LPG – meaning that raw biogas is not an option. This off course limits the number of local partners available.

After having had several meetings with Østkraft, Nexø Halmvarmeværk and Bornholms forsyning discussing potential project setups, we were down to the following potential partners that on an overall basis were interested in the project.

- **CEE/DTU**
- **Dantherm Power A/S**
- **Ballard**
- **Primagaz**
- **Green Hydrogen**
- **Nexø Halmvarmeværk**
- **Bornholm Forsyning**
- **Ecogrid.eu project and Energinet**

The interest from Østkraft A/S was limited and the possibility to rise funding was valued as critical.

This means that from the original reference group (which can be viewed in the proposal) Topsoe Fuel Cell is out, and there is no need to try and include biogas plants in the project proposal. We have spoken to BioGasol who was planning to build a test plant of 2 generation ethanol near Åkirkeby on Bornholm. They could be interesting to include in the project since they will have waste hydrogen available. However the BioGasol ethanol project on Bornholm was abandoned due to lack of the necessary funding.

None of the contacts showed willingness to co-fund the continuation of the project.

1.3.5 WP 5:

Identification of hosting partners (large units), user/consumers (small) and optimal sites (grid study):

From the grid study in WP1 we have that a good spot for locating the large unit including electrolysis would be on the Nexø Halmvarmeværk. In Nexø there would also be the opportunity of selling the excess heat from the process to the district heating grid. The pictures below are taken from a visit/meeting at Nexø Halmvarmeværk discussing their possible inclusion in the project.

For the small CHP units we haven't yet started to look for hosts – since the financing should be in place first. Østkraft was very reluctant to participate in financing.

1.3.6 WP 6:
Identification of sources for co-financing of next phase:

Østkraft A/S which is vital and major player in a materialized project - after a couple of meetings clearly expressed interest in using a cleaner/greener fuel than LPG for the individual CHP's. An all green full solution Dantherm Power cannot supply at the moment, so the focus of the project shifted to the larger unit and the financing of this.

Since none of the partners could finance the "own financing" part of a PSO, EUDP or EU supported MW project, which would cost between 50 and 100 Mio DKK, depending on which exact solution and setup we choose. Therefore we started to look into scaling the project significantly down in size. This would off course make the unit less use full for phase regulation and sinking/sourcing power in the Bornholm grid – but the learning's from including a smaller system in a SmartGrid concept would still be significant.

We ended up with much smaller project setup which is illustrated below:

This much smaller setup would cost approximately 10Mkr. and would include following project elements and partners:

Project elements:

- "Large" PEM unit: 20 kW PEMFC.
- A large CHP unit will be place in connection with a district heating power plant in the eastern part of Bornholm as demand for stabilizing the grid there is the strongest.
- The large CHP will include an electrolysis part for producing hydrogen from electricity, a storage tank for hydrogen and a fuel cell part for producing electricity from the stored hydrogen.
- The interaction with the grid (sinking and sourcing) will include both active and reactive power.
- In the smaller CHP unit the focus will be on grid support. The power inlet and outlet will be conditioned to stabilize both the grid supply and demand as well as active and reactive power. The reclaim of heat loss will be part of a theoretical calculation and not included in the experimental part. This due to cost considerations.

Project Partners and their contribution:

1. Dantherm Power
    - Project management
    - Fuel cell systems:
2. DTU / CET
    - SmartGrid expertise
    - Grid integration
3. Østkraft
    - Grid owner
    - Power customer
4. Bornholms forsyning, Næxø Halmvarmeværk
    - Owner of district heating grid
    - "Theoritical" Heat customer
    - Hosting equipment
5. Green Hydrogen
    - Supplier of electrolysis equipment
    - Responsible for hydrogen storage
6. Ballard A/S, Denmark
    - Fuel cell stacks
7. Siemens
    - Power electronics supplier.
8. Energinet.dk
    - Integration with ECOGRID project

The financing of even a smaller project like the one described above needs public support in order to have the slightest chance of materializing. As written earlier we have discussed EUDP, PSO and regional funding opportunities such as the European Regional fund, Innovation and knowledge – which is administered by a region and "Erhvervs og Byggestyrelsen¨.

We also looked into the possibilities to apply for a project within the EU FP7 program and the calls being published by the Joint Technology Initiative (JTI) of Fuel Cells and Hydrogen (Dantherm Power is a member). During this search Dantherm Power discussed a potential project setup with German and Belgium suppliers Hugo Vanden Borre, who could bring extra value and financing into the project. However these discussions never turned into a project.

The many discussions we had with the reference group about setting up a project never materialized – primarily due to the fact that Østkraft which is an essential player in a materialized Bornholm project – backed out and couldn't allocate the time, money and other resources to be involvement in the project. They instead decided to concentrate their resources on the originally planned Ecogrid.eu project.

During this search for additional project partners and financing, Dantherm Power off course didn't stop looking for partners for a project that included our 1 kW CHP systems. We got in touch with a number of major European Players, and ended up with applying the FCH JU for funding of a CHP demonstration project including 26 partners including manufacturers, utilities, research institutes and universities. The demonstration is to take place in several European countries and will include demonstration of 128 Dantherm Power µCHP systems. The project was funded and the project was initiated in Q4 2012. Even though this is not at SmartGrid project – the Dantherm Power participation in Ene.field, can be seen as a spin off to this SmartGrid Bornholm pre project.

1.4 Utilization of project results

The SmartGrid FCCHP pre project ends with this report. However Dantherm Power has learned a lot from this project, and has increased the development focus upon the alternative fuels – especially Biogas, which is a commonly accessible fuel in Area 4 in Denmark - and in other countries as well.

Dantherm Power are in cooperation with South African Anglo Platinum in the process of developing and testing a 2,5 kW home generator - capable on running on LPG and methanol. Later this platform will be adapted to our µCHP systems. Then the µCHP systems will have extra capacity available – and will be able to supply reserve power. These systems will not be finished within the first years – but is an example of what can be expected of FCCHP's as a SmartGrid technology in the years to come.

Dantherm Power has been working with the DONG version of SmartGrid in the Danish micro Combined Heat and Power project, and are actively pursuing inclusion in both Danish and European SmartGrid Projects. Last but not least the Dantherm Power participation in the European Ene.field project can be seen as a spin off from this project.

On the CEE/DTU side the experiences from this project are being carried forward into other projects. Currently, a PhD project is addressing the flexibility offered by a 1.2kWel FCCHP. This work will continue for another 1½ year. Another student project will address the cloud based service complying with the 61850 communication standard. Results and experience feed into a summer school focusing on new and alternative energy planning. On-going work is carried out on combining all distributed resources (DER) on a single 61850 based platform together with among others, the solar inverter/panel and the EV's. Further, a new EU (FP7-ICT-2013) project was proposed (CEE involvement) focusing on ICT, the 61850 standard and in particular investigating cloud based services which is capable to exploit the current tele-infrastructure.

1.5 Project conclusion and perspective

The results from this pre-project show that it is technically possible to integrate FCCHP units in a SmartGrid project on the island of Bornholm. The FCCHP potential for balancing fluctuating energy sources by sinking, storing and sourcing electricity is definitely present – at least for the larger units which include electrolysis.

The best place to host such units will be on the eastern side of the island, as the need to balance the grid is the strongest. A more specific location could be "Nexø Halmvarmeværk" where it would be possible to sell the heat to the district heating grid". Dantherm Power will be able to provide large FCCHP systems from 20 kW to 6 MW (in multiple of 5, 50 or 333 kW), and has excellent references in the area.

For the smaller CHP units (app. 1-2 kW electric) which within the timeframe of the Ecogrid.eu project has to be fuelled by LPG (liquid propane gas), technical changes has to be made to the µCHP products in order to provide the necessary services to the grid operators. Among these proposed changes are extra electric capacity and a move away from the current heat load operation mode. Both issues are dealt with by CEE/DTU and Dantherm Power outside this project.

After having had contact with a number of potential partners, and having tried to scale the project down to the current economic reality, we unfortunately had to skip the materialization of our plans, partly because it wasn't possible to find the necessary co-financing, and partly because a vital player in a materialized project (Østkraft) couldn't allocate the necessary resources to the project.

It is off course disappointing that the consortium couldn't make a SmartGrid project with Fuel Cells materialize on Bornholm. However this project has definitely contributed with valuable learning, and the efforts being put into the research at CEE/DTU and with the increased focus at Dantherm Power on developing products for inclusion in SmartGrids, we are certain that we will see both larger FCCHP's and micro CHP's in future SmartGrid demonstrations.

Attached to this final report is an article written and published by EEC/DTU as a part of this project "Integration of Fuel Cell Micro-CHPs on Low Voltage Grid".

1.6 References

[1] Østergaard, J. and Nielsen, J. E, "The Bornholm Power System: An Overview", 2008

[2] Energinet.dk, "Technical Regulation 3.2.1 electricity-generating facilities of 11kW or lower"

[3] You, S, Marra, F and Træholt, C, "Integration of Fuel Cell Micro-CHPs on Low Voltage Grid: A Danish Case Study", IEEE proceedings APPEEC 2012

[4] Energinet.dk, "Technical Regulations 3.2.6 Wind Turbines connected to Grids with Voltages below 100 kV"

[5] Energinet.dk, "Technical Regulations 3.2.3 Technical Regulation for Thermal Power Station Units of 1.5 MW and higher"

[6] Energinet.dk, "Proposal for a SmartDrid DK - Readiness Statement".

[7] PhD thesis "Real-Time Analysis of an Active Distribution Network" by Seung Tae Cha, 2012.