Final Project Report - PUBLIC

Project full title:	**Demonstration of MicroCHP Based on Danish Fuel Cells - Phase 3**
Grant agreement no.:	**The Danish Energy Agency (EFP-Akt.167 J.no. 033001/33033-0333)**
Project duration:	19 December 2008 to 31 December 2014
Project coordinator:	Kristina Fløche Juelsgaard

Contributors to the Final Report:

Kristina Fløche Juelsgaard (SEAS-NVE)
Thomas Engberg Pedersen (COWI)
Laila Grahl-Madsen (IRD)
Jan de Wit (DGC)
Ole Søgaard (SEAS-NVE)
Per Balslev (Dantherm Power)
Aksel Hauge Pedersen (DONG Energy)
Michael Byllemos (SE)
Magnus Larsson (Topsoe Fuel Cell)
Lotte Engberg Pedersen (Topsoe Fuel Cell)

SUMMARY AND CONCLUSION

This report summarizes and presents the conclusions on the project "Danish MicroCHP based on Danish Fuel Cells – Phase 3", covering the last phase of the project 2009 – 2014, including the field demonstration for:

- H_2-fuelled LT-PEM units at Vestenskov, Lolland (27 units)
- Natural Gas fuelled LT-PEM at Varde (20 units)
- Natural Gas fuelled SOFC in Sønderborg (2 units)

It succeeds the final reporting for phase 1 in 2008 and phase 2 submitted in 2012.

The final reporting consists of the following parts:

- The main report (this report) summarizes and evaluates the overall project, addressing general and cross-cutting topics. The main report is made available to the public.
- Three technology reports evaluating in detail the process and the results of phase 3 of the demonstration of each of the three technology tracks; LT-PEM(NG), LT-PEM(H_2) and SOFC. These reports are confidential and content of the reports may only be shared within the Consortium.
- Appendix – documenting the required deliverables

Conclusion on the results

Through this project, Denmark has strengthened its global market position on fuel cell technology. Especially for LT-PEM technology, good results have been achieved. The overall intention of the project has therefore been fulfilled.

Three technology tracks have been developed, demonstrated and analyzed throughout the three project phases (2005-2014). Experience and lessons learnt from phase 2 have been integrated in the improved designs of phase 3. The two LT-PEM technology tracks have focused on large-scale demonstration and long-term testing in the field, whereas the SOFC technology track has focused on developing a viable microCHP unit for installation at real end users in small scale (2 units) for a shorter period of time.

Throughout the long project period, including years of global financial crisis, one consortium partner has left the project (Danfoss), one technology track has changed (HT-PEM → LT-PEM(NG)), reformer technologies have changed, inverter suppliers have disappeared from the market and a great number of unexpected technological, political and societal obstacles turned the project into a roller coaster ride with plenty of ups and downs.

In conclusion, the partners are closing the project having obtained a successful demonstration, lots of valuable knowledge and lessons learnt for the next steps towards pre-commercialization, a strong cooperation amongst significant Danish industrial partners and a positive feedback on system performance from the most important critics – the end users in the private households.

Not all project targets were met, delays were inevitable, but in Phase 3 of the project it all came together through excellent team spirit and cooperation within the consortium group and with the three municipal hosts in Lolland, Sønderborg and Varde.

Table 1: Key project targets from the project description.

		Varde	Vestenskov	Sønderborg
		LT-PEM natural gas	LT-PEM H_2	SOFC natural gas
Electrical efficiency	(%)	35	50	45
Total efficiency	(%)	80 (+10)[1)]	85 (+10) [1)]	85-90 (+10) [1)]
Availability	(%)	95	95	95
Power-up time, cold		45 minutes	1 minute	10 hours

1) *+10% is in condensing mode, low-temperature heating systems*

In general, the Varde and Vestenskov technologies came very close to the electrical efficiency target. The Vestenskov, and especially the Varde installation, also met the target for total efficiency. The SOFC units did not meet the electrical efficiency target during field tests; figures of 38 and 42% were seen during continuous production. During the laboratory tests of the SOFC units, maximum electrical efficiency was measured to 44%, which came closer to the project goal. One SOFC unit met the total efficiency target for non-condensing mode by achieving 85% during continuous production.

The technologies did not meet the availability goal, if the average figure is used. However, for the Vestenskov case, a number of units did reach the target; for the Varde installations many units ended with relatively high figures of availability seen over the complete test period. A learning curve was seen in Varde, and during the last months of the tests, 58% of the units met the target.

The SOFC-based units did not meet the availability targets.

More details on performance of the individual technology track can be found in the track-specific reports for LT-PEM (NG), LT-PEM (H_2) and SOFC or the Technology comparative report D16.3.1.

Socio-economic studies have been carried out with the following, bleak conclusions:

- When analyzing the energy system in 2020, the electricity production from natural gas-based microCHPs mainly substitutes centrally coal-based electricity production. This shift from coal to natural gas, together with the increased energy efficiency due to increased co-generation of electricity and heat, results in a reduction in CO_2 emission as well as a reduction in socio-economic cost in the system. The reduction in costs should be compared to the extra annual capital costs of establishing the microCHPs instead of only gas boilers.
- The socio-economic feasibility of the hydrogen-based microCHPs is heavily dependent on the amount of wind power in the energy system and the variations in electricity prices. When analyzing the energy system in 2020, there is no business case for hydrogen-based microCHPs. In a system with much more wind power and possible problems with curtailment of wind power, the business case would be improved as the hydrogen-based microCHPs can utilize electricity from the wind turbines, which would otherwise be curtailed, and provide electricity e.g. in periods with no or limited wind.
- Denmark has a strong tradition for fuel-efficient combined heat and power production. Therefore, any substitution or supplementary technology must be fuel and power production-efficient. The power production from the microCHP units should primarily replace remaining fossil fuel-based power only-production at centralized plants to achieve fuel and CO_2 savings. The share of such power-only production has been declining in recent years.

Bringing the technology further on to the market meets two challenges: technical issues and market acceptance.

Technical issues relate to reducing cost and increasing lifetime and reliability of the microCHP units. Such improvements would all help strengthening the value proposition of microCHP units compared to alternative solutions. Research, development, demonstration and volume production methods are still needed to bring microCHP in a favorable position.

The fuel cell is not mainstream technology, and market acceptance is lacking. MicroCHP units provide efficient heat and electricity production at the physical location where it is used resulting in lower losses. In addition, microCHP will provide CO_2 savings (if fossil fuel-based power and heat is substituted) and the possibility of taking part in grid balancing. These three qualities are demanded by society.

When a private homeowner invests and uses a microCHP unit (s)he should be compensated for delivering these three qualities. The microCHP could be accepted faster in the market, and volume/cost balance could really start to take off for microCHP units in Europe. The Danish Micro Combined Heat and Power project is a first small step in this direction.

International perspectives and market analysis have been carried out with the following conclusions:

- The Danish case for microCHP for private houses meets challenges and so does the Danish market framework for introducing this technology. Far more attractive from an investment point of view are the market conditions in Germany or overseas (USA, JAPAN)
- In Denmark, decreasing gas prices and the decrease in prices on power-balancing services at present leave very little (no) economic incentives for end users or for electricity or gas companies to invest in this technology.
- Japan is leading the way, globally. Two attractive incentive structures are identified for successful market entry. Direct investment support to the end user or an attractive feed-in tariff for the produced electricity have proven to be efficient means for early market entry in Japan and USA.

MicroCHP has been identified as a possible contribution to the national smart grid vision. Therefore, smart grid operability has been introduced along the way, allowing for the following conclusion:

- LT-PEM-based microCHPs are basically suitable for smart grid operation, due to the short response time and ability to start and stop often. The hydrogen-fuelled microCHP shows the best results for frequent starts/stops and for the shortest response time (<1 min).
- SOFC technology is not suited for frequent start-stop operation and response times from cold starts are very long (hours). However, it offers good, continuous base load operation and has indicated useful variable load operation.
- The market for power balancing and power backup services always looks for providers of flexibility, but the price levels are currently very low, indicating that there is a limited need for further regulating capacity. However, the political goals for more wind energy integrating within the next five years call for more power balancing and backup services, where microCHP is an option.

Balance of Plant (BoP) components have generally been a challenge in the field test to all three technology tracks. The experienced failures and outages are typically not related to the fuel cell stack or the PowerCore, but were mainly caused by the failure of one or more of these BoP components:

- Inverter products – all relevant inverter manufacturers have strategically turned their production towards solar PV applications, which are not suitable for microCHP.
- Data collection and remote control – weak or insufficient tele network coverage in the rural areas made monitoring and controlling the microCHP units very difficult, causing many, unnecessary and long outages and many service visits.
- Hydrogen supply – unstable hydrogen supply caused the units to stop. The hydrogen supply was not part of this project.

The consortium partners have all gained from the project in the following way:

Dantherm Power (DTP): This Project is a major step on DTP’s roadmap for microCHP. Lessons learnt are relevant and applicable also to solutions within supplementary power and mobile systems. It supports DTP’s strategy to become the leading development center for Ballard in Europe.

COWI: The project has provided increased insight into fuel cell-based microCHP units (state-of-the-art) as well as their integration in the overall energy system, both for hydrogen-based units and natural gas-based units. This is in particular relevant in COWI's work with energy planning, energy system analyses, benchmarking and incentives structures for different technologies.

DGC has an interest in such new gas appliances with a key focus on efficiency, safety and environmental impact. As a side benefit of the project, DGC improved their internal processes of CE certification and laboratory testing procedures along with strengthening their hydrogen expertise.

DONG Energy: Initially the primary goal for DONG Energy was to increase gas sales. During the projects, additional interests in smart Grids and VPP operation developed and knowledge was gained. A direct benefit is to be harvested from introducing a new gas unit for households on the market, after further maturing of the technology.

IRD Fuel Cells: The developmental leaps from phase 1 throughout phase 3 have resulted in an immediate sale of custom-made components to other system assemblers. Integrating the lessons learnt from the field test helps to focus on further price optimization and prolonging life time expectancy.

Topsoe Fuel Cell (TOFC): Strengthened integration skills from the close TOFC-DTP cooperation. The knowledge obtained from the SOFC microCHP track also led to a strategic closure of that technology track at Topsoe’s, focusing on SOEC systems going forward, but integrating the lessons learnt from developing and testing the SOFC microCHP.

SE: Strengthened expertise in electrical and internet installation in the households and dealing with special meters and metering and billing conditions for customers with own production based on natural gas (not renewable).

SEAS-NVE: Knowledge about customers with oil boilers and their considerations about alternatives to oil. New knowledge about electricity storage and hydrogen solutions as an essential future activity in Power and Energy systems. Direct benefit is harvested on the close customer relationship experience and on the project management and coordination role.

The participating public contributors (municipalities and project sponsor) have gained from this project in the following way:

Varde Municipality: Was motivated to gain inside experience in facilitating a creative environment for testing and demonstrating new technologies in the local area. The administration's experiences in how to plan and communicate new green energy activities in the local area.

Lolland municipality: The strategic concept of Community Testing Facility (CTF) was tested and proven efficient with this project, supporting the municipal energy planning and boosting of local businesses and increasing green energy awareness.

Sønderborg Municipality: The goal of facilitating green growth technology projects was met. The knowledge gained is incorporated in the strategic energy planning processes.

Energistyrelsen/EUDP: despite the challenges and delays in the process, it has proven a successful project where requirements in research, development and demonstration have been met.

Continuation of the strong collaboration and "friendship" between consortium partners calls for more co-created development projects especially regarding BoP components. As the fuel cell technology has matured significantly throughout this project into a pre-commercial stage, a more commercial and competitive atmosphere amongst the technology partners has developed. Nevertheless, all partners agree that cooperation is still necessary to further develop and commercially mature the technology before entering the fully commercial market scene.

In this regards, only Topsoe Fuel Cell has bailed out of the technological race, due to its unexpected closure of all fuel cell activities for power production by the end of 2014. Topsoe Fuel Cell will cease to exist, but Haldor Topsoe continues the work with a focus on electrolysis and thereby utilize the knowledge gained from this project.

Project management

With four annual steering committee meetings, bi-annual workshops for the extended consortium with relevant guest participants and bi-annual progress reporting in a good dialogue with EUDP, the process of progress reporting change management and team building was smooth and effective. Despite the long project period of the entire project, the involved key people are more or less the same. Despite the participants' very different background and role in the project, a common understanding of project goal and common interest in reaching all goals drove the positive team spirit and made the participants succeed as a group.

Photo 1. Partner Group (with guests from EUDP and Energinet.dk) at workshop in Svendborg, July 2014

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1. INTRODUCTION

The idea of a Danish microCHP project began in 2005 with the ambition to develop, produce and demonstrate three different fuel cell-based microCHP technologies for household installation. The pre-work on planning and forming the project proposal was sponsored by Bitten and Mads Clausens Fond. Phase 1 of the project was kicked off in March 2006 based on the DKK 9 million support from ForskEL project program under Energinet.dk. The overall vision of this project is to support and utilize Danish Fuel Cell expertise to boost Denmark as a technological global leader in fuel cell technologies for household application, to create a new labor and skill intensive industry in Denmark, to reduce CO_2 emissions through efficient fuel utilization and to support the increasing integration of renewable energy sources into the national energy systems.

MicroCHP is in many ways a useful technology. In household installations, the units can substitute conventional boilers contributing to more energy-efficient heating. Due to the benefits of the co-production of electricity and heat, the technology also offers more fuel-efficient, CO_2-friendly and flexible heat and power supply to the household. This flexibility benefits the homeowner but also the electricity distribution grid, where foreseen capacity challenges call for central as well as decentral flexibility solutions.

In this relation, the interoperability between microCHP and grid controller is of importance. MicroCHPs can therefore play a significant role in the national smart grid vision. This project has included an additional target to test the technology for smart grid suitability and demand-response operability.

The original aim for the project was to install and demonstrate a total of 100 fuel cell microCHP systems in three phases in Denmark. The following Danish industrial players joined forces in the Consortium “Dansk Mikrokraftvarme” to realize the project.

- COWI, responsible for a study about socio-economic impacts for implementing a large number of microCHP units in the Nordic energy market.
- Dantherm Power, responsible for the design and construction of all the natural gas-fuelled microCHP systems.
- DGC, responsible for risk analysis of the appliances, CE certification and laboratory performance testing of these. DGC carried out analysis based on the field test data transmitted.
- DONG Energy, responsible for gas installations in Sønderborg and Varde for demonstration of natural gas-based units.
- IRD Fuel Cells A/S, responsible for the design and construction of the hydrogen fuelled microCHP
- SEAS-NVE, responsible for demonstration of LT-PEM (H_2) units in Vestenskov, including the production and supply of hydrogen.
- SE, responsible for demonstration of natural gas-based units in Sønderborg and Varde.
- Topsoe Fuel Cell, responsible for developing the SOFC-based “PowerCore” integrated in the SOFC microCHP together with Dantherm Power.

Financing the project

The Danish MicroCHP project phases 2 and 3 were planned during phase 1. The first phase was partly sponsored by Energinet.dk by a DKK 9 million grant. Phases 2 and 3 were partly sponsored through The Danish Energy Authorities by a special provision from the Danish Minister for Transport and Energy, Flemming Hansen:

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Transport- og Energiministeriet. København, den 12. juni 2007.

a. Transport- og Energiministeriet anmoder om Finansudvalgets tilslutning til, at tilsagnsrammen for § 28.72.02. Tilskud til energiforskning forøges med 50 mio. kr. i 2007 til fremme af projektet "Demonstration af mikrokraftvarme baseret på danske brændselsceller". Udgiften i 2007 finansieres af den på § 35.11.03. opførte bevilling.

b. Regeringen har i sin energiplan "En visionær dansk energipolitik" af 19. januar 2007 foreslået, at der i 2007 afsættes 50 mio. kr. til fremme af et konkret demonstrationsprojekt for brændselsceller.

Udvikling af brændselsceller har været et vigtigt indsatsområde i Energiforskningsprogrammet (EFP) i en årrække, og i juni 2005 fremlagdes en strategi for udvikling og demonstration af brintteknologier i Danmark.

Projektet "Demonstration af mikrokraftvarme baseret på danske brændselsceller" samler de førende danske industrivirksomheder inden for brændselsceller til kraftvarme (Danfoss, Dantherm A/S, Topsøe Fuel Cells, IRD Fuel Cells A/S, Powerlynx, DONG, Dansk Gasteknisk Center (DGC) og Cowi Consult). I mikrokraftvarmesystemer er strømproduktion placeret helt ude ved varmeforbrugeren. Små decentrale strøm- og varmeproducerende anlæg forventes placeret hos den enkelte forbruger til erstatning af de nuværende naturgasfyr.

Projektet er delt op i tre faser. I fase I (2005-2007) er der bygget to prototypeanlæg for mikrokraftvarmeanlæg, mens der i fase II (2007-2008) bygges ca. 10 mikrokraftvarmeanlæg, som sættes i drift under beskyttede forhold på kraftværker. I fase III (2008-2012) bygges op til 100 mikrokraftvarmeanlæg som placeres i to til tre demonstrationsområder i Danmark hos almindelige forbrugere.

Både Energistyrelsen (via Energiforskningsprogrammet) og Energinet.dk (via PSO-programmet finansieret over el-tarifferne) modtog i 2004 ansøgning om støtte til projektet. Ansøgningen blev behandlet og koordineret af forskernetværket under Energistyrelsen og Energinet.dk. Ved årsskiftet 2005/2006 blev projektets fase I tildelt støtte under Energinet.dk.

Også fase II er vurderet støtteegnet. Fase III kan ikke beskrives endeligt før projektets fase II er iværksat og der er indsamlet erfaringer fra fase I.

Fase I har et totalt budget på 14,9 mio. kr., hvoraf den private medfinansiering udgør 5,9 mio. kr. Fase II har et totalt budget på 38,6 mio. kr., hvor ansøgning om offentlig støtte er på 20,4 mio. kr., mens den private medfinansiering udgør 18,2 mio. kr.

Det samlede budget for projektets fase II og III skønnes til 125-140 mio. kr. En styrkelse af indsatsen i fase II og III med 50 mio. kr. kan sammen med den private medfinansiering sikre, at projektet kan gennemføres i sin helhed frem mod 2012. Tabel 1 viser projektets samlede projekt.

Tabel 1. Brændselscelleprojekt – budget, mio. kr.

	Offentlig støtte	Privat finansiering	I alt
Fase I	9*	5,9	14,9
Fase II	20,4**	18,2	38,6
Fase III	29,6***	56,8-71,8	86,4-101,4
I alt	**59,0**	**80,9- 95,9**	**139,9-154,9**

*: Midlerne er tildelt.
*: Midlerne er ansøgt og forventes at udgøre en del af de 50 mio. kr.
***: Under forudsætning af at der tildeles 50 mio. kr. til projektets fase II og III

Udmøntningen af de 50 mio. kr. foreslås administreret efter retningslinierne i lov nr. 1024 af 23. december 1998 om Statstilskud til forskning og teknologisk udvikling på energiområdet. Efter denne kan tilskud gives til forskning, udvikling og i visse tilfælde demonstration.

Dispositionen kan specificeres således på under- og standardkonti i 2007:

§ 28.72.02 Tilskud til energiforskning
10. Udbygning af dansk energiforskning og -udvikling
Udgift
45. Tilskud til erhverv .... 50,0 mio. kr.
§ 35.11.03 Reserver til højt prioriterede områder
10. Forskning
Udgift
49. Reserver og budgetregulering .... -50,0 mio. kr.

c. Forslaget forelægges Finansudvalget på nuværende tidspunkt med henblik på at kunne yde tilsagn til projektet i 2007.

e. Under henvisning til ovenstående anmoder Transport- og Energiministeriet om Finansudvalgets tilslutning til, at der på forslag til lov om tillægsbevilling for 2007 opføres følgende:

§ 28.72.02 Tilskud til energiforskning .... 50,0 mio. kr.
§ 35.11.03 Reserver til højt prioriterede områder .... -50,0 mio. kr.

f. Finansministeriets tilslutning foreligger.

FLEMMING HANSEN

/ Søren Wille

Til Finansudvalget.

Tiltrådt af Finansudvalget 21-6-2007.

For phase 3, the total public funding was planned to be DKK 29.6 million. The private financing of phase 3 was planned to be DKK 56.8 – 71.8 million. However, as the development of the technologies proved more costly than excepted, the private share of the total costs has by far exceeded budget. The development of the SOFC technology track proved more difficult and time consuming than expected, resulting in fewer SOFC units in the field demonstration, and therefore a reduction in public funding in this phase.

2. DEMONSTRATION RESULTS (COMPARISON)

Risk analysis and CE certification

Before entering field tests, all three types of units passed a risk analysis (HAZOP). Also, the units went through a CE certification process, as during field tests the units are placed outside the laboratory environment at third-party costumers. The CE certification included further risk analysis, documentation of components used and third-party laboratory tests related to gas safety and EMC compliance.

Performance testing and results for phase 3

In connection with the installation in laboratory for the CE certification-related tests, precision performance tests were also performed with a focus on production, consumption, energy losses and emissions for all three types of microCHP units. These tests were performed at the DGC laboratory. The test results are reported in separate Work Package reports. The results from the field tests of the three technology tracks are as follows:

- In the Varde area, two units were pretested in municipality buildings followed by installation of a total of 20 natural gas-fired Dantherm Power units deployed during phase 3 in private households; all of these natural gas-fired units are based on LT-PEM fuel cell stacks.
- In Vestenskov on Lolland, a pretest with five IRD units was first made in five private homes; later, another 27 IRD units were installed and tested in homes and public buildings. All the Vestenskov units were fuelled by hydrogen.
- In Sønderborg, two SOFC-based high-temperature microCHP units were installed and operational by mid-2014. These were based on the Topsoe Fuel Cell PowerCore; balance of plant (BoP) and integration was made by Dantherm Power.

Figure 1 presents operational results for the units over the final phase 3 test period. The 20 natural gas-fired units in the Varde region achieved a total of more than 125,000 hours of operation; the hydrogen-fired units in Vestenskov achieved a total of more than 90,000 hours of operation (DGC received data from 72,000 hours) including the early phase 3 test with a limited number of units.

To some extent, the operating time of the units in Vestenskov was limited due to problems with the hydrogen production equipment, which led to limited hydrogen availability in some periods. This had an influence on the operating time achieved and possibly also on the availability and the number of faults. The operation of the units in Sønderborg was limited due to malfunctioning inverters, a stack breakdown (partly mal-operation) and limited demand for the heating produced due to a warm summer and autumn.

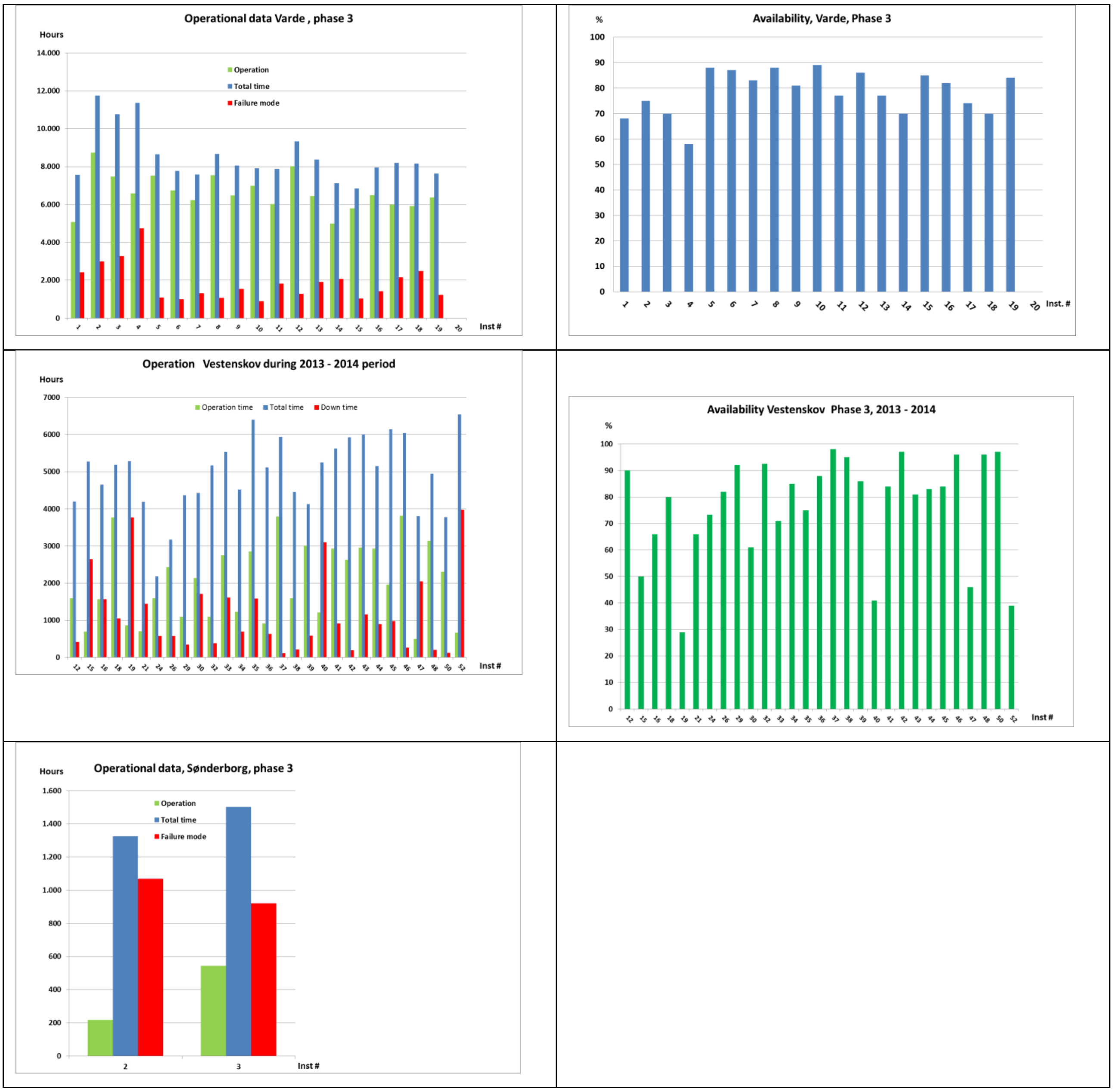


Figure 1 The overall operational field test data for three different types of units. The presentations are based on data transmitted and available to DGC. Five of the units in Vestenskov achieved higher operational figures than shown, as they had an early pretest period in phase 3.

The units with the highest number of hours of operation during the phase 3 tests were a unit in Varde with close to 8750 hours of operation (but was stopped as the field test period ended) and a unit with more than 10,000 hours of operation in Vestenskov.

The availability of the units was in the range of 58 – 89% for the complete Varde area tests (on average 78%) and 29 – 98% for the Vestenskov tests (on average 77%). A learning curve could generally be seen leading to higher availability (on average >95%) in the later part of the tests for the Varde units. The availability of the units in Sønderborg was low seen over the actual test period. This was due to technical problems as mentioned above, the closure of the stack/PowerCore supplier Topsoe Fuel Cell during the test period and a reduced interest from the system integrator to support a system in which the core technology is no longer available.

Efficiency measured during the field tests can be seen in Table 2. All efficiency results shown refer to the lower heating value (LHV) of the fuel.

Table 2 Efficiency measured during the field tests. (Continuous operation, Lower Heating Value (LHV) reference)

	Net electrical efficiency (%)	Total efficiency (%)	Fuel
Varde	3 - 35	92 - 102	Natural gas
Vestenskov	42 - 49	N.A.*)	Hydrogen
Sønderborg	38 – 42	78 – 85	Natural gas

*) Data not available, malfunction of the heat meters installed.

The electrical efficiency results measured during field tests are close to the targets set up in the project description. The electrical efficiency results are very high compared to any competing power production technology for the actual power output range.

The total efficiency results are generally high and in fact higher than the project target for the Varde units. They are relatively low for the Sønderborg SOFC units. This is due to the fact that a high operating temperature and a relatively large surface area lead to surface losses. This is also due to the fact that the SOFC units operate with a very high air-to-fuel ratio, leading to reduced possibilities for energy gains via flue gas condensation. However, the efficiency of the Sønderborg SOFC units is very high compared to similar systems developed.

In general, the most difficult components during the field tests were the DC-AC converters. They proved difficult to buy, they came with a limited technical support and they were unexpectedly sensitive to disruptions on the power grid. Lightning caused many failures, outages and the need for man assisted restart. Moreover, local grid related power quality issues, such as start of electrical power tools/compressors nearby etc. sometimes led to failure of operation. The actual fuel cell stacks had very few failures; however, stacks could be damaged as a result of other component failures. This picture of difficult components is also reported from field tests of Japanese fuel cell-based microCHP units.

The annual CO_2 savings obtained per unit was typically in the range of 1.2 - 2 ton for the natural gas-fired units in the Varde region. In Vestenskov, even higher CO_2 savings (0.5 – 3.7 ton) were obtained as no fossil fuel hydrogen was used. The units in Sønderborg did not operate for a complete season/year.

Examples of own coverage of electricity and heat in the private houses measured during the phase 3 field tests are shown in Table 3.

Table 3 MicroCHP production, in-house use, typical ranges on annual basis from the Varde tests.

	In-house use of the CHP electricity production	CHP coverage of house electricity needs	CHP heat coverage of house heating needs
	%	%	%
Varde Area	50 - 90	30 -70	20 - 40

In most private houses, the net electrical production from the microCHP units was less than the annual electricity consumption. However, an ‘export’ of power was seen during some periods when the actual power need was lower than the power production from the microCHP unit. This was the case as the operation of the unit was mostly controlled by the demand for heat, a feature based on prior analysis.

An example of the monthly electricity need, the production from the microCHP unit and the electricity export can be seen in Figure 2.

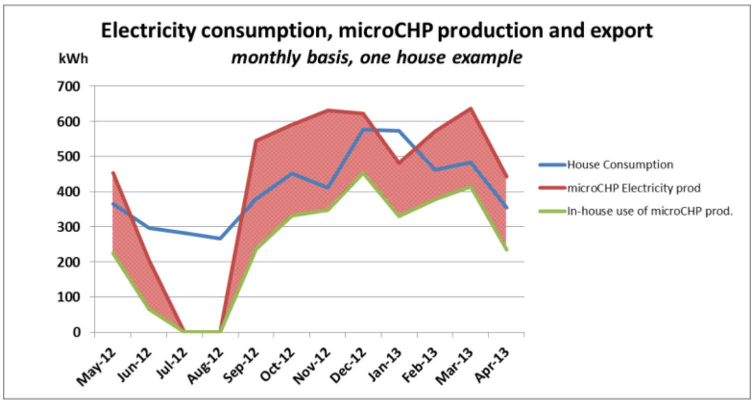


Figure 2 Example of monthly electricity need, production from the microCHP unit and in-house own electricity coverage from one house in the Varde field tests. The dotted area illustrates the part of the electricity that is exported to grid.

Fulfillment of project targets

Table 4 shows some key technical targets for the project.

Table 4 Key project targets from the project description

		Varde	Vestenskov	Sønderborg
		LT-PEM natural gas	LT-PEM H_2	SOFC natural gas
Electrical efficiency	(%)	35	50	45
Total efficiency	(%)	80 (+10)	85 (+10)	85-90 (+10)
Availability	(%)	95	95	95
Power-up time, cold		45 minutes	1 minute	10 hours

In general, the Varde and Vestenskov technologies came very close to the electrical efficiency target. The Vestenskov, and especially the Varde installation, exceeded the target for total efficiency. The SOFC units did not meet the electrical efficiency target during field tests; figures of 38 and 42% were seen during continuous production. During the laboratory tests, maximum electrical efficiency was measured to 44%, which came closer to the project goal. During field testing, one SOFC microCHP unit met the total efficiency target for non-condensing mode by achieving 85% during continuous production.

The power needed for heating up the SOFC-based units to their operating temperature (7 – 800^{o}C) will influence their net efficiency over a week if several starts and stops occur. The net electrical production efficiency of a week with 5-10 starts will end at 27-29% due to the power needed for heating up. Such units (SOFC) should therefore be used as base load units.

None of the technologies met the availability goals if the average figure is used. However, for the Vestenskov case, a number of units did reach the target; for the Varde installations, many units ended with relatively high figures of availability seen over the complete test period. A learning curve was seen in Varde, and during the last months of the tests an average availability of >95% was reached, thus meeting the target.

The SOFC-based units did not meet the availability targets.

All three technologies came close to the power-up time targets.

3. MAIN CHALLENGES

The challenges we are facing in bringing the technology further on to the market falls in two categories: technical issues and market acceptance.

Technical issues relate to reducing cost and increasing lifetime and reliability of the microCHP units. Such improvements would all help strengthening the value proposition of microCHP units compared to alternative solutions. Research, development, demonstration and volume production methods are still needed to bring microCHP in a favorable position.

During the Danish-microCHP project we have learned that a number of technical parts of the units need further development as to cost reduction and reliability improvements. Some examples of these are:

- DC/AC inverters dedicated to fuel cell applications. We have experienced in this project that the inverters developed for PV applications modified for fuel cell applications do not meet requirements and the price target needed
- Balance of plant (BoP)components used in the fuel systems need to be more integrated to meet the price and reliability targets
- Integration with the heating system of the house must be simplified to meet cost targets
- Cost reduction needed for fuel processing and de-sulfurizing of the natural gas system
- Hydrogen generation must become more reliable and cost of equipment must be reduced

The fuel cell is not mainstream technology and market acceptance is lacking. MicroCHP units provide efficient heat and electricity at the physical location where it is used resulting in significantly lower losses. In addition, microCHP will provide CO_2 savings and the possibility of grid balancing. Two qualities demanded by society.

When a private homeowner invests in and uses a microCHP unit (s)he should be compensated for delivering these two qualities. The microCHP could be accepted faster in the market, and volume/cost balance could really start to take off for microCHP units in Europe.

Another important barrier for commercialization is the lack of awareness among decision makers, which is reflected in the laws and regulations, e.g. hourly registration of produced power exported to the grid. There are still many challenges to be addressed before the technology can become fully commercial. Despite these challenges, the Danish MicroCHP project is a first small step in this direction.

4. END USER RELATIONS

With today's rules and regulation in Denmark, there is no financial incentive in exporting electricity produced by microCHP systems based on natural gas. To obtain an optimal end-user financial benefit, the microCHP systems must match household electricity consumption on an hourly basis. For the hydrogen-based microCHP systems, where the hydrogen is produced using mainly electricity from wind turbines, it is argued that the hydrogen is a renewable energy. These microCHP systems are therefore eligible for simple net settlement, benefitting the end-user.

Based on the experiences gained from the field tests, there are no functional issues in the coupling of the primary heat source and the microCHP system. The natural gas-based systems were installed as supplements to the existing natural gas-based heating source of the households. The hydrogen-based systems were installed as substitution for the oil boilers of the households, and therefore they operated in a stand-alone mode. However, these hydrogen systems were supported by electric water heaters to top up production in peak hours of demand.

The coupling of the microCHP with the heat storage facility in the houses operated successfully and improved the overall operating conditions and experiences by limiting the number of start-stops, which resulted in an increased flexibility in the electricity and heat production.

Net settlement

The electrical settlement method used in the field test of the microCHP was: "simplified net settlement Group 5" (Fixed installations where the exported electricity is zero or marginal) as described in the TSO (Transmission System Operator) guideline1 from Energinet.dk.

However, in Vestenskov, annual net settlement was used, and in Varde, hourly net settlement was used during the field test, which means that 'exported' electricity is subtracted from the 'imported' electricity on an hourly basis, whereby net house consumption becomes subject to billing. All exported electricity that is not used within the hour is delivered to the grid for free.

This billing method was chosen for the Varde field test as electricity produced from natural gas does not fall under the same privileges as renewable electricity, where the TSO has a production balance responsibility, and selling the electricity on the spot market would require a contract with a commercial production balance responsible entity and associated cost.

Primary / secondary heat source

During selection of the field test hosts it was ensured that:

- there was sufficient room to integrate the microCHP system with the existing heat source
- return temperature in the heating system was suitable
- routing of gas, water, exhaust and electricity was possible

The heat power of the primary heat source was typically 12-16 kW. The microCHP system was connected to the return pipe of the primary heat source. When the heat demand of the house

[1] "*Retningslinjer for nettoafregning af egenproducenter*" Energinet.dk document no.: 27582-10

exceeded the 1,6kW heat power of the microCHP system, the primary heat source supplied the additional heat demand. Hot water demand of the household was produced by the primary heat source only.

Ownership

Before the field test was started a lease agreement between the demo host and the involved parties from the consortium was signed.

For example, Dantherm Power leased the microCHP system in a min. period of 12 months to SE, who in turn leased the microCHP system to the test host. After the end of the field test all installation sites was re-established to state prior to the installation and the microCHP systems returned to Dantherm Power for further analysis (Post mortem).

All costs associated with the field test were covered by Dantherm Power, SE and DONG Energy. From the project the test hosts received extra payment for all exported electricity from the fuel cells and free natural gas for the fuel cells during the field test.

A similar (but not identical) constellation was applied for the end users in Vestenskov, where IRD Fuel Cells and SEAS-NVE covered the costs of the field test, leaving for the end users to pay for their actual heat and power consumption, based on the average energy rates for the last three (3) years.

The project revealed a possible administrative barrier for microCHP implementation. Energinet.dk's forms for small power producer registration only accept one type of production unit per producer. It is therefore not possible to be own producer of electricity from both solar panels and a microCHP in the same household.

5. SOCIO-ECONOMIC ANALYSIS

As part of the project activity on socio-economic analyses, a number of quantitative analyses have been carried out focusing on the direct benefit of the microCHP units. This benefit has been estimated by use of the system modelling tool Balmorel, which simulates the electricity and heat production in electricity and CHP systems. The analyses have been carried out for the scenario of year 2020.

For the natural gas solutions, a direct economic benefit of approximately DKK 740 per unit per year has been estimated (including CO_2 benefit). This socio-economic benefit should be compared to the extra annual capital costs of establishing the combined microCHP / gas boiler systems instead of only gas boilers.

Figure 3 and Figure 4 below show the change in electricity production by fuels, and the change in fuel use for electricity and heat production when introducing the **gas microCHP units**, which are replacing **individual gas boilers**. From Figure 3, it appears that the total electricity generation in the system is unchanged by the introduction of the gas-fuelled microCHP units, but an additional amount of electricity is produced by gas. From Figure 4 it appears that the introduction of the gas-fuelled microCHP units results in a net reduction in total fuel consumption in the system, which is due to increased co-generation of electricity and heat. The main fuel reduction is seen at coal-fired power plants.

Figure 3: Change in electricity production by fuels (positive equals increase)

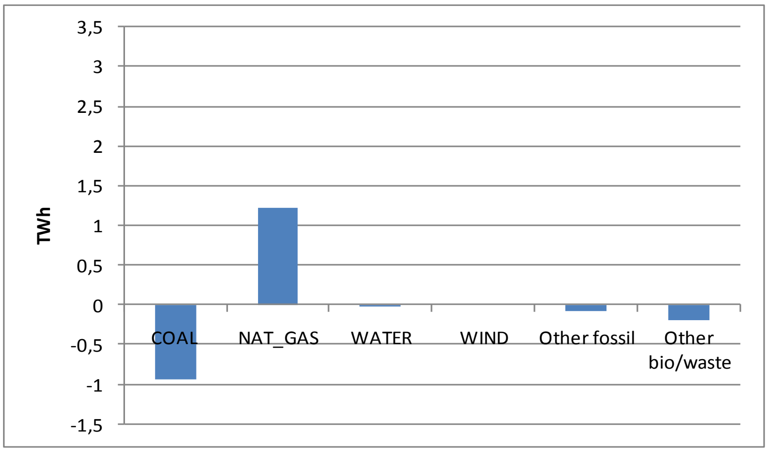
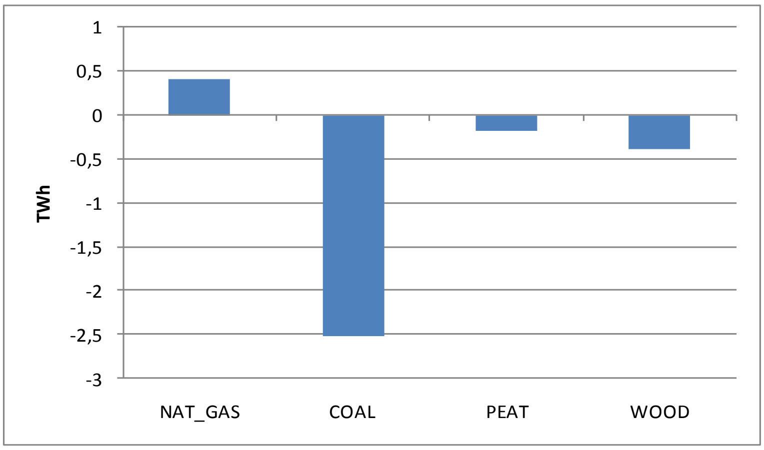


Figure 4: Change in fuel use for electricity and heat production (positive equals increase)



The hydrogen solutions are indeed very, and more than the gas solutions, dependent on variations in electricity prices. In situations where the microCHP units are not forced into operation, the model, due to among others the limited electricity price variations found in 2020, mainly chooses to produce the heat by the electric heaters. This is due to the relatively high losses in the hydrogen production and distribution system.

The direct economic benefit of the hydrogen solutions in combination with electric heaters as backup has been estimated from a loss of DKK 2,200 per unit per year up to a benefit of DKK 2,600 per unit per year. However, in the situation with at benefit of DKK 2,600, the benefit mainly arises from the electric heater which accounts for 90% of the heat production.

Figure 5 and Figure 6 below show the change in electricity production by fuels, and the change in fuel use for electricity and heat production when introducing the **hydrogen microCHP** units, which are replacing **individual oil boilers**. From Figure 3, it appears that the total electricity generation at thermal power producers in the system (and hydro) increases by the introduction of the hydrogen-fuelled microCHP units. This is due to the increased losses in the system (more electricity are used for hydrogen production than production using the microCHP units) and due to the fact that almost no excess wind, that would otherwise have been curtailed, is used for the hydrogen production in 2020. This result may have been different if a future situation with almost 100% of wind energy in the system had been analyzed instead of the model situation in 2020. From Figure 4, it appears that the introduction of the hydrogen-fuelled microCHP units results in a net increase in total fuel consumption in the system, which is due to the required increase in electricity production (arising from the losses).

Figure 5: Change in electricity production by fuels (positive equals increase)

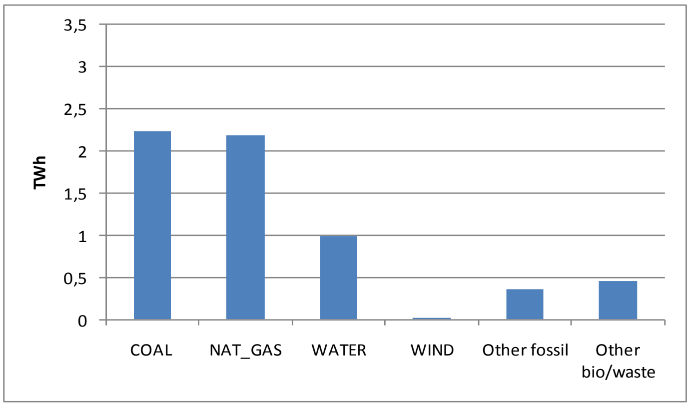
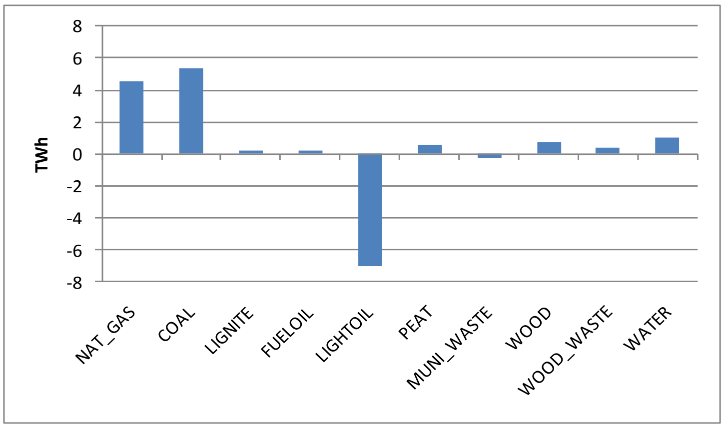


Figure 6: Change in fuel use for electricity and heat production (positive equals increase)



The direct economic benefits and the CO_2 reductions are shown in the table below. The direct economic benefit includes the benefit/costs of reduced/increased CO_2.

DANISH MICRO COMBINED HEAT & POWER
Heat & Power from Fuel Cells

Table 5 Socio-economic benefit and CO_2 reduction by scenarios.

	Direct economic benefit (reduction in socio-economic costs) [million €]	Reduction in CO_2 (which is also included in the direct economic benefit) [ton]
Natural gas	301	855
Hydrogen	338	-1199
Hydrogen, forced	-869	-2196
Hydrogen, double wind	1035	-713
Hydrogen, double wind, forced	214	-1448

It appears that the two hydrogen scenarios without forced production at the CHP units are the scenarios with the highest direct economic benefit. However, these two scenarios are actually rather two "electric heating" scenarios than two hydrogen CHP scenarios as the electric heaters produce most of the heat in these scenarios. It also appears that the CO_2 emission actually increases in the hydrogen scenarios, which is due to the increased need for electricity production, and due to the fact that in 2020 only a very little amount of wind energy, which would otherwise have been curtailed, is used for hydrogen production.

The model results have illustrated a very central point. Without having very large variations in electricity prices from some hours to others, the hydrogen solutions cannot compete with electric heaters (or heat pumps for that matter), which in combination with heat storages also have a relatively high flexibility with respect to using electricity when electricity prices are low.

When talking about the future electricity market, it can on one hand be argued that further development of wind power will lead to more fluctuating electricity prices. On the other hand, there are a lot of measures under development with the purpose of utilizing electricity when prices are low and reducing electricity consumption in peak-load hours when prices are high. One of these measures is the hydrogen microCHP units. Other measures are electric vehicles, heat pumps and demand response. The development of these measures will - opposite to the wind power development - lead to less variation in electricity prices. Therefore, it is difficult to say whether electricity prices will be more or less fluctuating in the long run, compared to today's prices.

In the analyses of the hydrogen solutions, it has not been taken into consideration that, depending on the location of the electrolyser, it may be possible to utilize the heat loss in the electrolyser for heat production. In some cases, this may increase the direct economic benefit of the hydrogen solution compared to the figures in the table above.

In addition to the direct economic benefit shown above, there may be some other socio-economic benefits for both the gas and hydrogen solution. These are:

- Reduced electricity distribution losses and costs
- Increased regulating power capacity
- Reduced investment costs at other power plants in the system
- Increased security of supply
- Increased possibilities of incorporating wind power in the system

Not all these other benefits (additional to the direct economic benefit) are additive. For instance, if some investment costs are saved at other power plants in the system, the CHP units will not contribute to an increase in the overall security of supply at the same time. But the list of benefits points out some relevant aspects that, apart from the direct economic benefit, may contribute to the total socio-economic benefit of the microCHP units.

6. SMART GRID READINESS

Smart grid means 'computerizing' the electric utility grid. It includes a two-way digital communication technology between the devices associated with the grid and the utility's network operations center. A key feature of the smart grid is automation technology that lets the utility adjust and control each individual device or millions of devices from a central location. However, fulfilment of the smart grid vision also requires that the individual device is aimed at fast response and is sufficiently robust to cope with many start-stop cycles. The latter aspect is investigated in further detail within the present project.

Response time is of vital importance in a smart grid context. The hydrogen-fuelled microCHPs demonstrated in Vestenskov took 2.5 min. to reach full power from cold conditions, while the equipment can be shut down in less than ½ min. The power-up time can be reduced significantly by including batteries or super-capacitors to compensate for the power output during the power-up, a well-known technology for hydrogen-fuelled UPS systems based on PEM fuel cells. During the field demonstration in Vestenskov, several hydrogen-fuelled microCHPs were scheduled for up to 12 daily start-stop cycles. The overall conclusion is that the cell degradation is not related to the number of start-stop cycles (Fig. 7) and that the hydrogen-fuelled microCHPs are well suited in this respect to become part of the future smart grid.

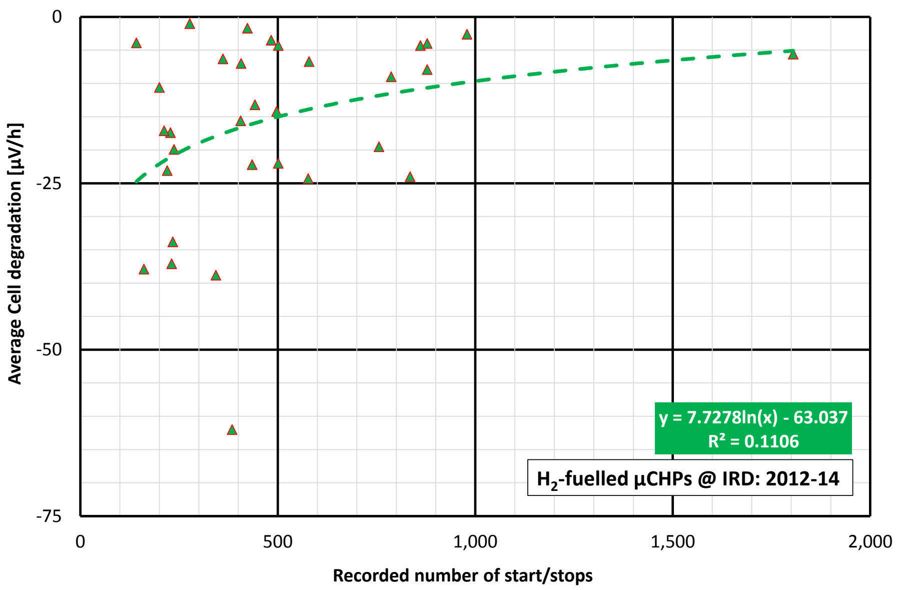


Figure 7 Average cell degradation versus number and start-stop cycles for individual hydrogen-fuelled microCHPs demonstrated in Vestenskov 2013-2014

In Varde, selected microCHP units were controlled by the DONG PowerHub, which was integrated in the microCHP systems' control system. The DONG PowerHub setup is designed to interface power producing hardware to the secondary reserve power market in Denmark.

During February to April 2013, a series of three tests controlling four microCHP systems for a period of 60 hours were performed, in which the communication was made over the existing internet connection. The microCHP units' power-up time of approximately one hour means that only units already operating can meet the 15 min. requirement, for reaching full power, set on the secondary reserve power market. For the reformer-based fuel cell systems deployed, the optimum solution for delivering regulating power would be to bid in excess capacity while the system is running.

With the current bidding volumes on the secondary reserve power market ±15MW and a microCHP system size of 1kW, a third-party provider pooling the systems in a virtual power plant (VPP) is needed.

If this theoretical setup was performed, an optimistic estimate of annual system earnings would be DKK 680-970. Dividing this earning between the system owner (end user), the VPP operator and the energy company in a business model, in which the profit follows the allocated risk, it is most likely that only a small fraction of the total profit could be left for end-user incentive. The setup of a suitable business model was outside the scope of this task.

7. INTERNATIONAL PERSPECTIVES

In an international perspective, there are higher expectations for the fuel cell-based solutions than any other directly competing microCHP technologies. According to the internationally recognized technology analyzing institute Delta-ee (http://www.delta-ee.com) the global microCHP share for engine-driven microCHP solutions (Stirling and gas engine) has dropped from 100 to 30% from 2008 to 2013. On the other hand, fuel cell-based solutions have increased their global microCHP market share from 0 to 70% for the same period of time.

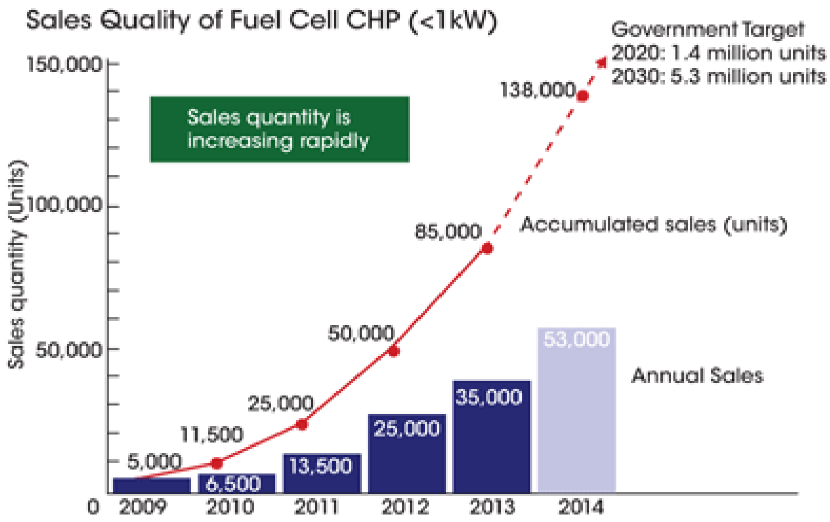


Figure 8 MicroCHP Fuel Cells in Japan

The numbers only reflect a few hundred thousand plants, and it is mainly Japan (see Figure 8) - and partly Korea - which have been successful, with many thousand plants installed. In September 2014, Japan passed a remarkable milestone with 100,000 fuel cell-based microCHP units, where both the European and the US market are lagging far behind with only a few thousand systems installed.

The reason for the lack of international success is primarily the high costs. The high costs are due to production costs for the units, costs for operation and maintenance and a lifetime that does not quite meet the commercial benchmark, primarily defined by condensing gas-fired boilers. Continued development of the fuel cell-based microCHPs and mass production of these will solve these obstacles on the way to a commercial breakthrough for the markets in the US and Europe. However, it is acknowledged today that it will take longer than previously anticipated. Just a few years ago, expectations indicated several million microCHPs in the European market by 2020, but today the same expectations are down to perhaps 100,000 plants in 2020.

Therefore, a commercial breakthrough will depend on a continued public support for many years ahead.

Danish MicroCHP in an international perspective

The Danish demonstration project for fuel cell-based microCHP has received considerable international attention. The project and results from the project have been presented internationally at several occasions, and a lot of foreign visitors have come to Denmark to visit the demonstration sites. Globally, this project - along with the corresponding German Callux project - represent the most important demonstration projects for microCHPs in recent years. A somewhat larger European demonstration project - ene.field - with 1000 demo installations in 12 EU countries has recently been started up, but the foundation for the project is experiences from Callux and the Danish MicroCHP projects.

As an additional element in the Danish microCHP project, the "clean hydrogen solution" was introduced – a feature that no other international demonstration projects have yet included. The combination of wind-based hydrogen production to feed fuel cells in microCHP installations is a technology meant for the future fossil-free society. The commercial breakthrough is probably not imminent, but the Danish microCHP project has demonstrated the solution, and therefore this particular part of the project attracted much international attention.

8. INDUSTRIAL PARTNER PERSPECTIVES

The microCHP plants are expected to become a significant part of the future renewable energy system. For this reason, the project has focused on the interaction between the units, the consumers (demo-hosts) and the utility companies. Valuable knowledge for the further deployment has been obtained. As a result of the successful completion of the demonstration project, both IRD Fuel Cells A/S and Dantherm Power A/S are now ready to bring their technology further towards commercialization. The commercialization plans include installation of 3,000 microCHP plants in Denmark before 2018. The planned distribution comprises 1,500 hydrogen-fuelled plants and 1,500 natural gas or biogas-fuelled plants. The microCHP technology still needs to become more market mature. This will happen in parallel with the production of more units. The Danish commercialization will take place in close competition with other, international fuel cell microCHP providers, particularly with manufacturers in Japan and Germany.

A further price reduction of 50% is expected for both IRD and Dantherm Power microCHP systems by 2018 as a consequence of a higher production volume. Furthermore, the additional operational experience that will be obtained during the operation of the many plants on the local markets in Denmark is a prerequisite for obtaining the necessary lifetime warrantees that are needed to expand to the international markets. Fuel cell-based microCHP has great export potential. The annual market for boiler replacement units is more than DKK 100 billion in Europe alone. Danish produced microCHPs aim at winning up to 10% of the potential European market for boiler replacements. This will result in an annual Danish export of up to DKK 10 billion and holds a great potential for Danish growth and creation of Danish jobs.

From a first glance, many new technologies appear attractive from an environmental and energy-related point of view, but it is a tough task for new technologies to penetrate the market. There are many reasons for a possible commercialization failure or a slow breakthrough. Among the key barriers is the high financial risk related to the challenge of providing a long warranty period. Furthermore, at present, the high microCHP investment costs are not justified in Denmark by the owners of flexible power production, the environmental benefits of replacing fossil fuels are not credited nor is energy security via smart grid services financially appreciated. This means that there is no financial incentive or even justification for the technology, although it can be an important method for grid balancing.

Integrated microCHPs are recognized as one of the most mature of fuel cell systems. Several European manufacturers are ready for large-scale distribution. Already, a few European companies sell products, though mostly under public support programs; other companies participate in large-scale field tests like the present Callux project in Germany or ene.field across Europe.

A successful Danish fuel cell-based microCHP industry still needs political acceptance and support, as has been the case for the wind industry for many years. Financing measures may be different, but it is crucial for the energy strategy/policy implementation, job creation and the export potential.

9. DISSEMINATION

During the course of the project phase 3, the vision, the progress and the results have been shared with interested parties in the following way:

Publications

Articles in magazines

1. Mikrokraftvarme på brint i Vestenskov, Gasteknik 5/2014,
2. Micro-CHP - A tool for increased market access, Cogeneration and On-Site Power Production, May-June 2014
3. Mikrokraftvarme i praksis, Gasteknik 6/2013
4. Mikrokraftvarme er succes – nu skal prisen ned, FiB 44, april 2013
5. Test af mikrokraftvarme i stor skala i private hjem, Gasteknik 3/2013,
6. Mikrokraftvarme – tæt på gennembrud, Nyhedsbladet Dansk Energi, 11/2012
7. Klar til mikrokraftvarme med naturgas, FiB 38, december 2011,
8. Klar til mikrokraftvarme med naturgas, Gasteknik, 5/2011,
9. Brint og brændselsceller til mikrokraftvarme, Dansk Kemi 91, 12/2010
10. Brændselsceller til mikrokraftvarme – det danske projekt, HVAC 11/2010
11. Fem familier luner sig med brændselsceller, Electra, april 2009
12. Brændselsceller til mikrokraftvarme, HVAC 1/2009

Articles in public newspapers and magazines

A media analysis for the entire project period has been performed. A total of 323 media events targeting the broader population has been registered. Most eager journalists are from the local newspapers of Vestenskov, Varde and Sønderborg, as shown in figure 9.

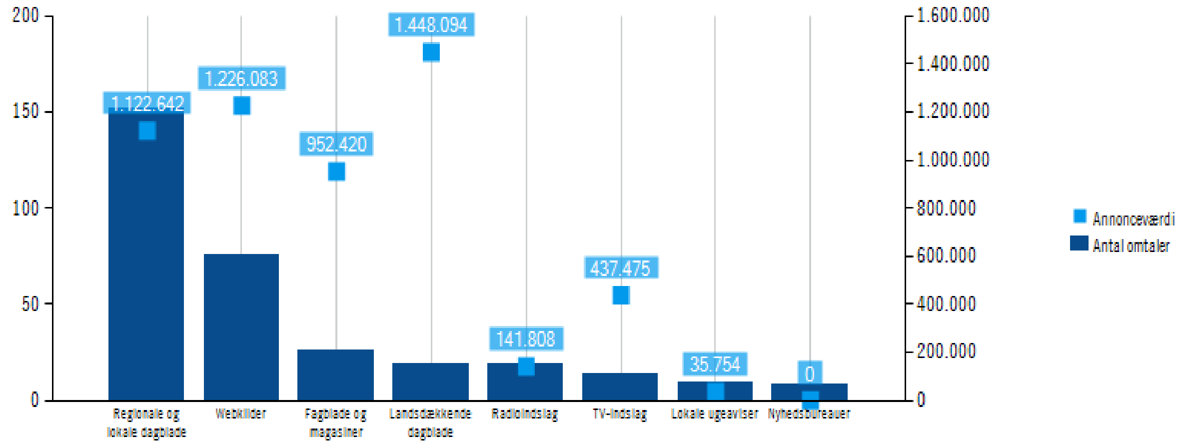


Figure 9 Media events for Danish microCHP project 2007-2014 (source: Infomedia)

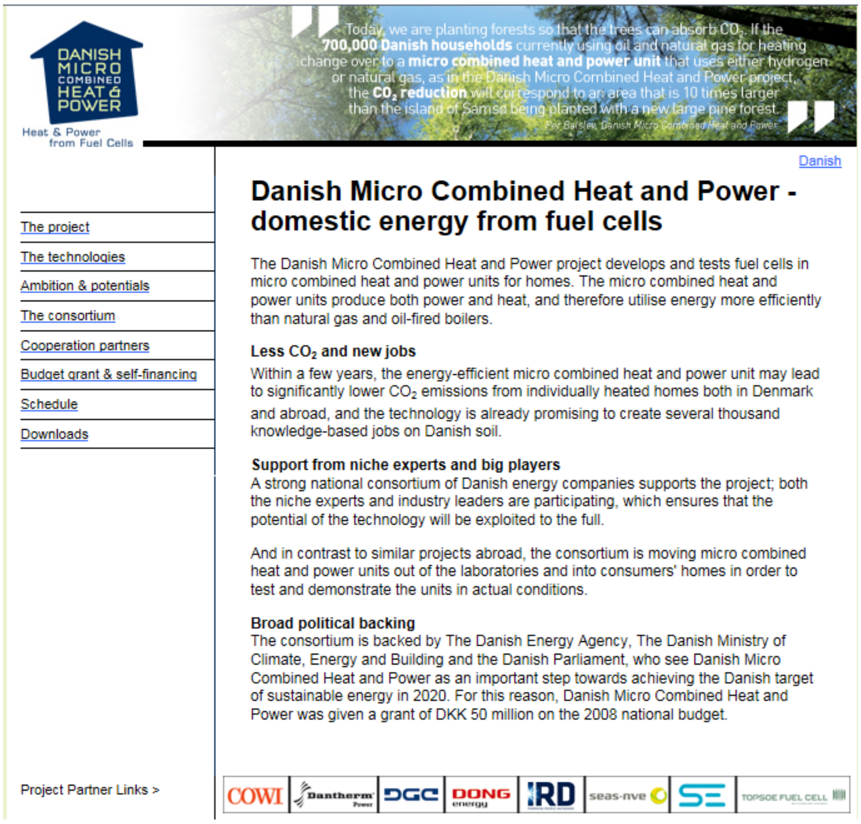
Conference presentations/papers

All project partners have been very eager to present the project at various Danish and International conferences. Only the international presentations are listed here. For further detail, please refer to the technology reports.

1. Development and demonstration of Danish fuel cell based micro cogeneration, M. Näslund, J. de Wit, DGC et al., 3rd International Conference on Micro-cogeneration and Related Technologies, 15-17 April 2013, Napoli
2. MicroCHP units meeting tomorrow's power/heat demands and improving the integration of renewables, J. de Wit, DGC et al., Power-gen Europe, 4-6 June 2013, Vienna
3. Residential Fuel Cell Micro Cogeneration - Opportunities and Challenges in the System Design, M. Näslund, J. de Wit, DGC et al., International Gas Research Conference 2008, Paris
4. PEM Fuel Cell Power for Stationary Applications, Laila G. Madsen, IRD et al., Conference and Trade Show, 2007, Vancouver.
5. MicroCHP implementation, M. Näslund, J. de Wit, DGC, Power-gen Europe 2007, Madrid.
6. Implementation of microCHP in single-family houses, Jan de Wit, Ianina Mofid, Karsten V. Frederiksen, DGC, World Gas Conference 2006, Amsterdam.
7. FuelCellEurope Roundtable discussion on CHP, Laila Grahl-Madsen (2010) on the 25th of March, 2010 in Brussels
8. The Hydrogen Demonstration Society @ Lolland Island, Denmark, FCH JU general assembly, Laila Grahl-Madsen (2010): November 9-10, Brussels
9. Fuel cell Durability & Performance conference, Hydrogen fuelled PEM µCHP's in field test in Denmark Laila Grahl-Madsen (2010), Poster presented 9-10th December, 2010, Boston
10. Real-life experience obtained in Vestenskov during field test with hydrogen fuelled LT PEM µCHPs. L. Grahl-Madsen at the PEMFC Degradation workshop, Sintef Oslo on the 3rd – 4th of April, 2013.
11. International Conference on Fundamentals & Development of Fuel Cells, Karlsruhe, Germany on the 16th to 18th of April, 2013, L. Grahl-Madsen: Field experience with a Hydrogen fuelled µCHP.
12. Providing sustainable power and heat in Denmark and beyond. Oral presentation at the Danish-Korean PEM Fuel Cell Workshop, November 18-19, 2013, KIST, Seoul, Mikkel Juul Larsen (2013) IRD A/S
13. Development and demonstration of PEM FC based µCHP units in the hydrogen village Vestenskov on Lolland in Denmark. Oral presentation at the workshop on "Progress in PEMFC Stack Testing Procedures" organized by Next Energy on 28th – 29th of January 2014, Steen Yde-Andersen (2014)
14. "Development and Demonstration of Danish Fuel Cell based micro cogeneration", Presented at the 3rd International Conference on Micro-generation and Related Technologies, 15-17 April 2013, Napoli, Mikael Näslund, et al.
15. "Micro CHP units meeting tomorrow's power/heat demands and improving the integration of renewables", Power-gen Europe, 4-6 June 2013, Vienna, Austria, Jan de Wit et al.
16. "Micro-CHP - A tool for increased market access", published in "Cogeneration & On–Site Power Production", May-June, 2014, Jan de Wit, Laila G. Madsen and Mads Møller Melchiors

Dissemination Website

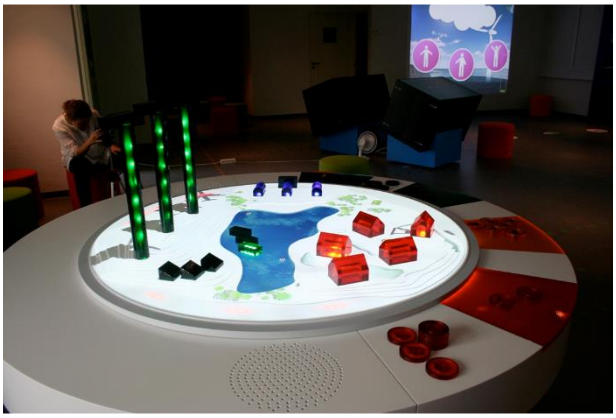
The project website (www.dmkv.dk) has existed since 2008. During 2011, the website was redesigned and restructured to reflect the progress of the project. Based on the expected future role of the µCHP units as a sustainable technology and in relation to smart grid, the website presents the fuel cell technology in relation to wind power, smart grid and different fuels as well as to the project content.



In 2014, the website was rearranged to act as an information source about the project and the role of the participants. All public presentations (papers, articles, reports) are now available for free download on the project website.

Exhibitions

In relation to the COP15 UN Climate Conference in Copenhagen in 2009, the exhibition house "H2Interaction" was opened, displaying the topics of fuel cells, hydrogen, microCHP and renewable energy in a popular and interactive way. The exhibition has been well visited, mainly by international delegations and industry, but also by Danish politicians and industrial leaders, schools, local activity clubs, tourists and citizens. A total of 160 delegations have visited the exhibition over the project period.



In addition, a temporary show case exhibition was displayed at the annual meeting of *Dansk Gasteknisk Forenings* (Danish Gas Association) in 2012 and at *Folkemødet* (annual political event for politicians, industry and the general public) on the island of Bornholm in 2013.
All exhibition activities have resulted in very positive feedback both from technical experts and ordinary citizens on the efforts to communicate technically complex material in a popular way.