Final report

1.1 Project details

Project title	SIMBA
Project identification (program abbrev. and file)	64013-0140
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	Ballard Power Systems Europe A/S
Project partners	Aarhus university
CVR (central business register)	30804996
Date for submission	18/06/01

1.2 Short description of project objective and results

A new generation of microCHP and supplemental power generator in the range of 2 kW has been developed. Critical components have been optimized especially in regard to fuel and water treatment which are essential to guaranty the proper operation of the machines. 2 separates platforms have been developed one operating on methanol fuel and the others on natural gas and liquid petroleum gas. Both platforms have been demonstrated in the field.

1.3 Executive summary

MicroCHP and supplemental unit generate electrical energy. Those products belong to the continuous power generator and high-density fuel is the only viable commercial option. Unfortunately, hydrocarbon contains molecules which can harm the catalytic process and deactivate the catalyst and shorten drastically the life time of the generators. A thorough investigation of fuel quality as well as fuel treatment solutions have been investigated. A novel design of pelletized adsorbents has been developed. The electrical interface have been designed by the implementation of complete hybrid interface based on Lithium ion battery. Finally the platforms were demonstrated internally and externally in order to gain as much learning as possible in order to optimized service and identify further potential cost reduction.

1.4 Project objectives

The objectives of this project are to create a concept design of generator capable to operate with different fuels and generate electricity in different outputs. It is to understand the fundamental around sulphur content in fuel and water reactants and develop a low cost desulphuriser unit. Finally, to demonstrate the technology platform capability through internal evaluation and external field trial.

1.5 Project results and dissemination of results

1.5.1 WP1 2 kW Concept design

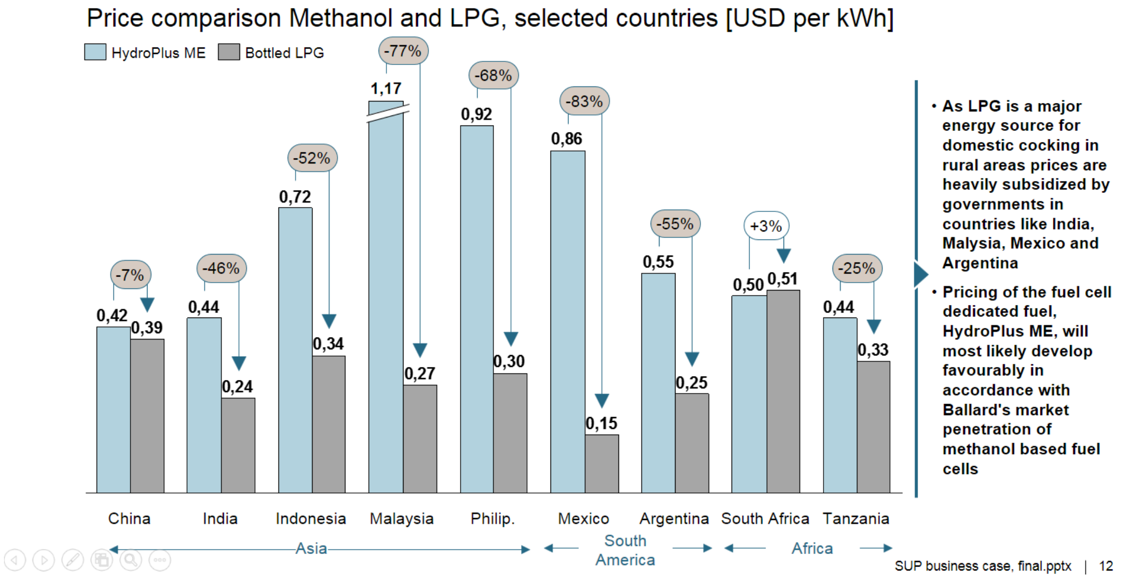
The design of the Simba platform has two main requirements. It need to be fuel flexible and offer different electrical interface configurations. The battery charger configuration is declined into two sub-configurations, 48 VDC battery charging or off grid AC with the addition of standard commercial sinewave inverters. The platforms should be able to operate on 3 fuels: natural gas (NG) or upgraded biogas, liquid petroleum gas (LPG) and methanol. The platform for NG and LPG is codeveloped with the USDAN project while the methanol platform utilized component from the Electragen product line developed by Ballard. The fuel used for the methanol system is based on a premixed of deionized water and methanol. All fuels are required to contained extremely low level of Sulphur in ppb level to guaranty a long-life time of the projects.

	Grid connected	Battery Charger
NG	✓	✓
LPG	✓	✓
MeOH		✓

The product is targeting two market segments. The supplemental or prime power segment and microchp segment. Both segments have a similar commercial life time, start/stops and price target which offer the possibility to decline one core product to serve 2 market segments.

	Supplemental	µCHP
Number of service/ year	1	0.5 - 1
Yearly Operating hours	4000	4000
Shut down	365.0	182.5
Product life time in (Operating hours)	40000	40000
Product life time (years)	10	10
Price	<10000 USD/kW	<10000 USD/kW

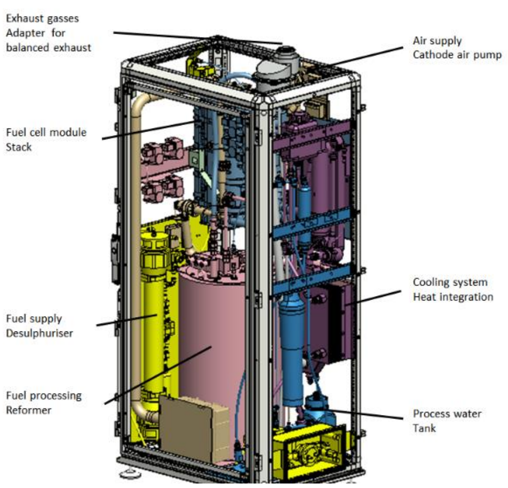
The fuel choice is governed by the fuel price which clearly indicate a significant cost benefit of LPG for supplemental power market. NG price is not shown here since it only applied to the microchp market segment.



2 platforms have been designed based on the following key specifications. Each system offers a versatile electrical interface. The FCgen H2C battery charger option utilize the DC/DC converter currently used in the H2 power product which offer additional reliability and cost synergies benefits.

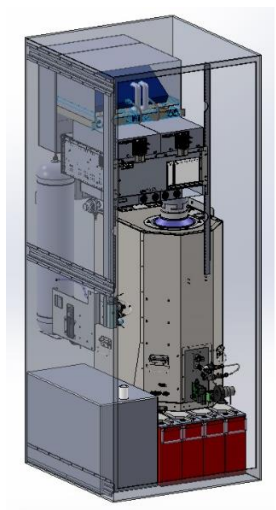
<u>FCgen-HC2</u>

- NG availability on site or LPG tank
- Grid connect (standard, Battery charger option)
- Heating interface access or radiator interface
- Drain possibility
- Remote monitoring via ethernet
- Sufficient space + service area (unit 600mm by 800mm by 1800mm)
- System weight 350 kg so we recommend ground floor level Balance exhaust < 6m (compatible for household market)



<u>Electragen ME 2.5 Compact:</u>

- 2.5FPM (but not including low standby power and weight reduction)
- MeOH/water tank integrated
- Control Module
- DC-DC Converter
- Manifolds & Fuel Delivery Module
- DC Interface Module
- Enclosure & Mounting of modules & options
- Fuel Cell Module (same stack)
- Plumbing, Wire harnesses, etc.
- Ventilation, Thermal Management
- FPM Exhaust
- Battery solution for bridge power

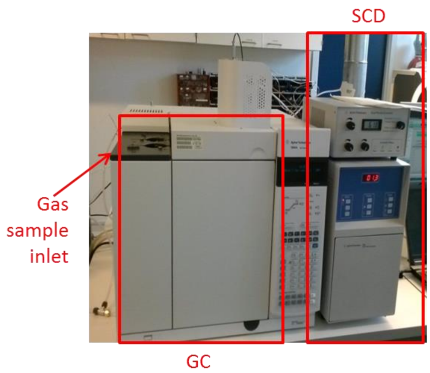


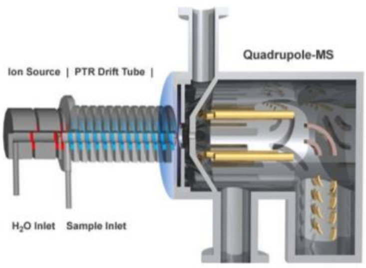
1.5.2 WP 2 Fuel and water

As mentioned previously, fuel (reactants quality) is essential to guaranty a long-life time of the project. While Sulphur remains the main poison, other compounds can also deactivate the catalyst. This is the case for Silica, halides (chlorine), hydrocarbons etc. The focus of the study is focusing on Sulphur contains in fuels and water.

<u>Measuring equipment:</u>

The measurement for sulphur compounds is based on Gas Chromatography using a Sulphur Chemiluminescence Detector (GCSCD). The sulfur compounds are separated by a GC-column based on their physicochemical properties. The eluate from the column is mixed with O2 and H2 and combusted at 800°C which produces reduced chemiluminescent sulfur species. These sulfur species then react with an excess of ozone to produce an excited state of SO2*. When this species returns to its ground state it emits light at a specific wavelength which can be measured. The instrument is thus highly specific for the detection of sulfur compounds. The method relies on identification of the sulfur compounds based on their retention times (RT). As the column is non-polar the approximate elution order of the compounds can be predicted roughly based on their volatility. However, a standard is required to identify the sulfur compounds with absolute certainty





<u>MeOH – Water mix requirement:</u>

The Electragen ME is operated with commercial grade methanol / water mixture. The objective of this study is to outline compounds that could jeopardize the long-life operation of the fuel cell system. For water content equivalent to a Steam to Carbon equal or less than 1.5.

	Molar	Volume – 20C	Mass
% methanol	>40%	>47%	>54%
% water	<60%	<53%	<46%

An initial assessment of the performance of the machine indicates that fuel consumption will be around:

	BOL	EOL
Water mass flow rate (g/min)	16.5	20.6
MeOH mass flow rate (g/min)	19.5	24.4
Water mass usage (kg/40000h at full load)	44520	
MeOH mass usage (kg/40000h at full load)	52680	

The potential contaminants from the fuel/water mixture need to comply with the process water pump, the FPS and the anode compartment contaminants requirement. While conductivity gives an indication of the level of contaminants, it is not sufficient to ensure a sufficient purity of reactants. The requirement has been assessed by performing some reverse engineering on contaminated catalyst and calculate the level of acceptable sulphur content.

Commercial methanol has sulphur content comprised between 10 ppb_w and 100ppbw. Based on 100ppbw, the sacrificial catalyst of the is 50%

	MeOH reformer – 2,5kw
Weight bed active (g)	1062
Sacrificial weight(g)	527
Sacrificial weight % of the active bed	49,6%
Sulphur uptake in % weight	1%
Total [S] absorbed (mg)	5268
Fuel [S]% in ppbw	100
Life time (h) (Sulfur from fuel only)	40000

Assuming that 50% of the source of sulphur is evenly shared between the water and the fuel, we can have determined the following reactant requirements.

	Sulphur content based on 50% sacrificial ratio
Methanol	< 50ppb
Water	< 50ppb

Water quality differs from region to region. It will have to be treated to comply with the preliminary requirement established above.

	Requirement (ppb_w)	Hobro (ppm_w)
Sulphur	50	3,6 (S of Sulphate, 11)

In terms of conductivity, the NG program required a quality of water below 0.1<µS/cm. This specification was established by Tokyo Gas. On the MFCA joint position document, it is stated that water should have a conductivity < 0.07µS/cm which is fairly similar and in line with the Japanese requirement. This lead us to water quality of grade 1 according to the ISO 3696 and type 1 according to the ASTM D1193-06.

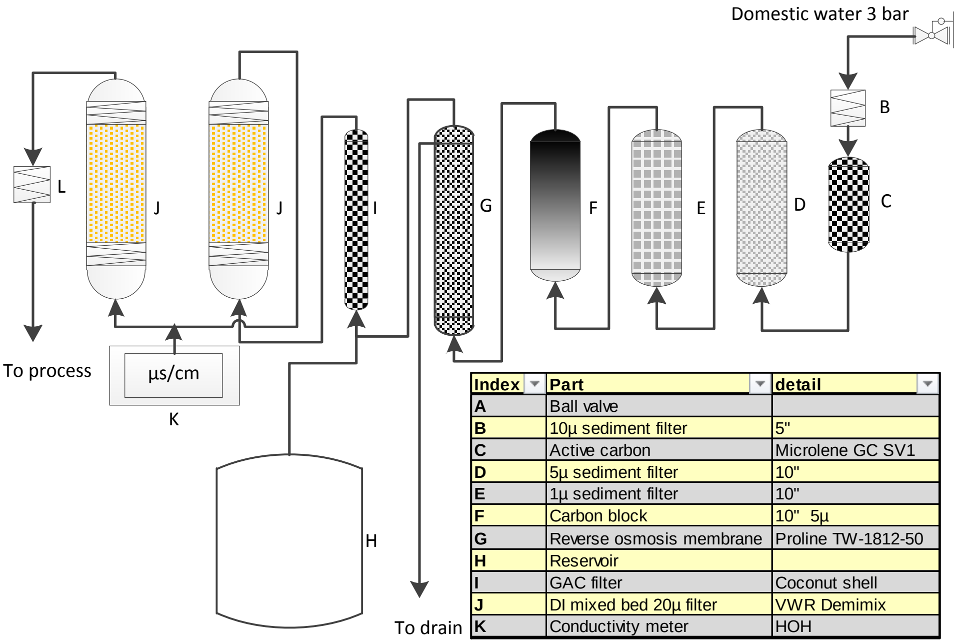
BS EN ISO 3696 water for analytical laboratory use

Parameter	Grade 1	Grade 2	Grade 3
pH value @ 25 °C	N/A	N/A	5.0 – 7.5
Conductivity, µs/cm @ 25 °C	0.1	1.0	5.0
Oxidisable matter Oxygen (O) content, mg/l	N/A	0.08	0.4
Absorbance @ 254 nm (1cm cell), abs units	0.001	0.01	NS
Residue 110 °C, mg/Kg	N/A	1	2
Silica (SiO^2), mg/l	0.01	0.02	NS

ASTM Standard specification for reagent water D1193 - 06

Parameter	Type I	Type II	Type III	Type IV
Resistivity, MΩ-cm	18.0	1.0	4.0	0.2
pH	-	-	-	5.0 - 8.0
Total Organic Carbon TOC, µg/l	50	50	200	-
Sodium, µg/l as Na	1	5	10	50
Chloride, µg/l as Cl	1	5	10	50
Total Silica, µg/l	3	3	500	-

This quality can be obtained by using a reverse osmosis membrane followed by DI polishing treatment. The set-up below described our installation in Hobro where we obtain consistently conductivity below 0.1 µS/cm using commercially available components.



Index	Part	detail
A	Ball valve	
B	10µ sediment filter	5"
C	Active carbon	Microlene GC SV1
D	5µ sediment filter	10"
E	1µ sediment filter	10"
F	Carbon block	10" 5µ
G	Reverse osmosis membrane	Proline TW-1812-50
H	Reservoir	
I	GAC filter	Coconut shell
J	DI mixed bed 20µ filter	VWR Demimix
K	Conductivity meter	HOH

The produced water was verified. The conductivity of the sample is measured in house at 0,058µS/cm at RT. Most of the compounds are below DL.

	TI		Eurofins	
		Method		Method
PH	5,8	DS 287	7,6	DS 287
Conductivity at 25°C µS/cm	0,99	DS/EN27888	<5	DS/EN27888
Na(+) mg/l	<0,1	Atomic adsorption	NM	
K(+) mg/l	<0,1	Atomic adsorption	<0,5	ISO17294m-ICPMS
Ca(2+) mg/l	<0,1	Atomic adsorption	0,66	ISO17294m-ICPMS
Mg(2+) mg/l	<0,01	Atomic adsorption	0,071	ISO17294m-ICPMS
Cl(-) mg/l	<0,1	Ion Chromatography	<1,0	SM17udg4500
NO(3-) mg/l	<0,1	Ion Chromatography	<0,1	SM17udg4500
SO4(2-) mg/l	<0,1	Ion Chromatography	<0,5	SM17udg4500
S(2-) mg/l	<0,01	DS278	<0,05	DS280:197 auto
HCO3(-) mg/l	6,1	Titration	<3,0	DS/EN I9963
F(-) mg/l	<0,1	Selective Electrode	<0,05	SM17udg4500
Al(3+) µg/l	<2	Atomic absortion	51	ISO17294m-ICPMS
SiO2 mg Si/l	<0,05	Spectrometry	<0,002	Grasshof
VOC, mg/l	<0,06	Combustion IR	<0,5	DS/EN1484
NVOC, mg/l	0,087	Combustion IR	<1,0	DS/EN1484
Methane	NM		<0,005	M0066GC/FID
Sulphur Total, mg/L			<2	DS259/SM3120ICP
Coliform bakterier 37°C MPN/100ml	NM		<1	Colilert
E coli, MPN/100ml	NM		<1	Colilert
Biofilm at 22°C CFU/ml			22	DS/I6222:2000
Biofilm at 37°C CFU/ml			22	DS/I6222:2000

Methanol quality

Different commercial grades are currently available on the market. In the US, a federal specification called O-M-232 is currently used and defined 2 different of grades, Grade AA used for H2 production and grade A used for solvent application. The ASTM D1152 as well as the M100 also provides a specification (M100 not shown in the table below and used in California). Finally, the IMPCA (International Methanol and Producers and Consumers Association) have developed their own methanol reference specifications. The table below captures their differences. The IMPCA specification which is the latest specification states Sulphur which are known contaminants for fuel cell and reformer and are not considered in the other specifications.

Parameter	IMPCA Reference Specification 09 Dec 2010	Grade A OM 232 L 04 Jan 2006	Grade AA OM 232 L 04 Jan 2006	ASTM D1152
Purity (wt %)	99.85	99.85	99.85	99.85
Appearance	Clear no sediment	Clear no sediment	Clear no sediment	
Color (platinum cobalt scale - maximum)	5	30	30	50
Specific gravity (20/20)	0.791 to 0.793	0.7928	0.7928	0.792 to 0.793
Water (wt % - max)	0.10	0.15	0.10	0.10
Acidity (as acetic acid mg/kg max)	30	30	30	30
Sulfur (mg/kg - max)	0.5			

This lead to a new specification which appear to be 10 times more stringent than the IMPCA and MFCA specifications.

Parameter	IMPCA Reference Specification Dec 2010	Fuel cell grade specification from MFCA Sep 2002	BPSE specification
Purity (wt %)	99.85	99.85	99.85
Appearance	Clear no sediment	Clear no sediment	Clear no sediment
Color (platinum cobalt scale - maximum)	5	30	30
Specific gravity (20/20)	0.791 to 0.793	0.7928	0.7928
Water (wt % - max)	0.10	0.15	<1
Acidity (as acetic acid mg/kg max)	30		30
Sulfur (mg/kg - max)	0.5	0.5	0.05

A design verification has been performed on two different commercial samples from Brenntag to assess if a commercial supplier is able to produce a fuel mix quality which comply with our requirement.

A first method based on direct injection MeOH mix was used but appeared that the GC column could not tolerate water containing samples. It damaged the column as well as the GC and it had to be repaired. A specific test method was developed called 'cold trap' where the temperature for the specific amount of methanol sample was increased, so all sulfur compounds and methanol were evaporated. Then nitrogen was introduced to transfer the vapor through an ice-cold trap, so methanol may have condensed as liquid again, but not Sulphur compounds. Finally, we collected all the nitrogen with Sulphur compounds and analyzed the gas sample in our GC-SCD.

	MeOH Conc. (%) W	Mass fraction MeOH	Density (kg/L)	Steam to Carbon ratio	SO2 (ppb_w)	DMS (ppb_w)	DMDS (ppb_w)	Sulphur total (ppb_w)
Sample1 (16/10-2015)	54%	0.54	0.907	1.52	ND	ND	2.5	2.5
Sample2 (12/11-2015)	62%	0.62	0.890	1.10	1.1	1.1	3.6	5.8

The result indicates that the commercial methanol water mix complies with the requirements. Further efforts will be required to ensure that it complies with other contaminants such as Halides or silica.

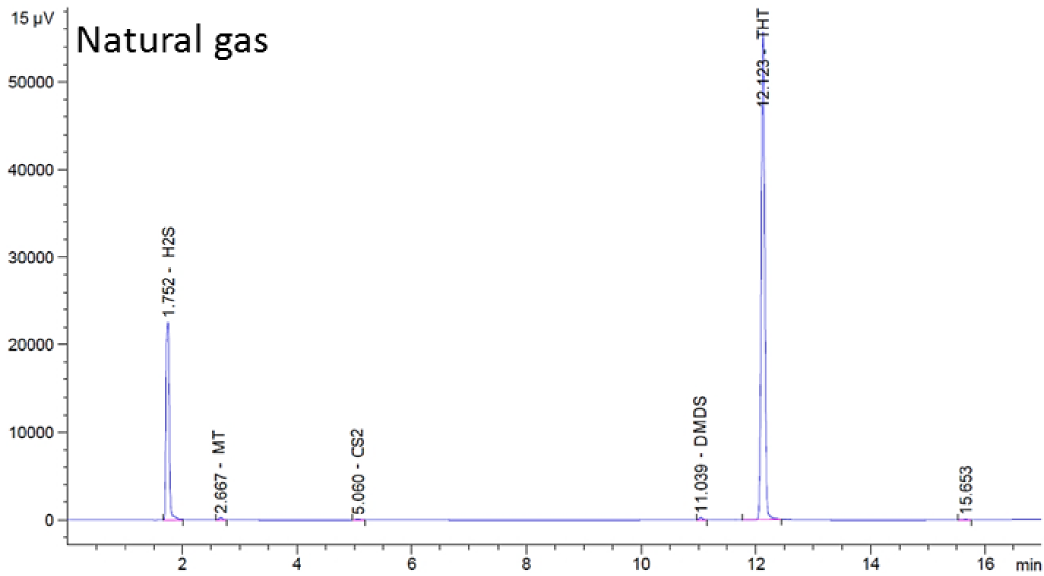
<u>Natural gas and LPG fuels:</u>

Sulphur concentration in NG or LPG is not constant and varies from region to region and also overtime. In natural gas two major types of sulphur compounds are typically present, hydrogen sulphide (H2S) which is naturally present and odorants like mercaptans (CH4S) or tetrahydrothiophene (THT) in natural gas. It typically varies from 1 ppm to 5 ppm. While measuring the sulphur content is possible at laboratory scale, it remains difficult to implement it in an actual system due to cost and reliability limitation. Therefore, an assessment of the sulphur content in different region is required. Two level of sulphur can be used, the actual sulphur content based on historical data and the regulatory content defined by local regulations. Additionally, two different business cases are considered: Micro CHP and supplemental power. Both business cases have in common the long product life time of 10 years as mentioned in WP1. The modelling study indicates that 24240 kg of natural gas is consumed per appliances for 40 000 hours of operations. If the appliances are operated on LPG, the latest model indicates the fuel consumption will be around 25079 kg of propane. The model is based on the 2 cases described below. The model is calibrated based on measured performance of the FCgen-HC2-mCHP and FCgen-HC2-sUPP.

	Amount of fuel to be treated in 40 000 hours of operation	
Fuel type	NG (DK)	LPG (DK)
Weight (kg)	24240	25079
Energy equivalent (kWh)	326634	332766

The natural gas and LPG fuel were analyzed using a GC SCD instrumentation. Water quality was not investigated since the FCgen-HC2 is water neutral meaning that it produces its own water. Water quality remains critical for LPG/NG systems but the contaminations sources are internal to the systems, the most important is to understand source of potential contaminants i.e catalyst aging, HEX corrosion. The fuel on the other end contains a certain amount of Sulphur compounds which has to be removed. The detection level is around 3 ppb_vol and the limit for a 40000 hours lifetime is around 5 ppb_w of total Sulphur. As part of this study commercial LPG from different regions have been analyzed as well as NG from Denmark. In the example shown below, we can see two different chromatograms, one for natural gas and one for LPG. Once calibrated, we determined the actual Sulphur content for each detected species. We can see that NG as well as LPG contains different compounds.

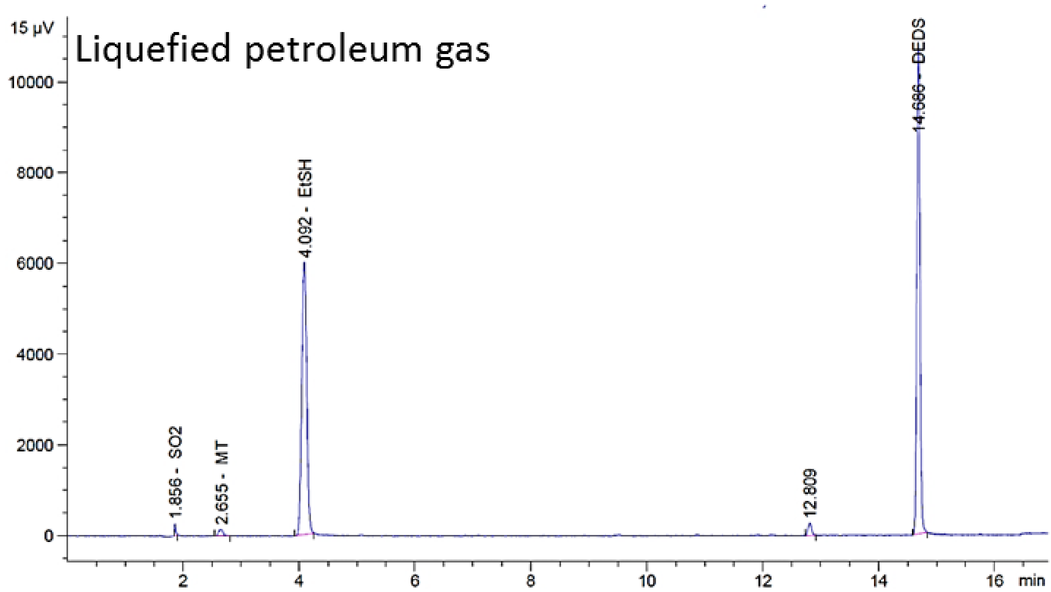
In the natural gas, five sulfur compounds were detected using the GC-SCD. H2S, methanethiol, CS2 and tetrahydrothiophene were identified based on their retention times, while the sulfur compound at retention time 10.64 min remains unidentified. On average, the four identified sulfur compounds constituted an estimated 99.7% ± 0.2% of the total sulfur compound concentration in the natural gas, with H2S and the artificial odorant tetrahydrothiophene representing 27 and 73%, respectively.



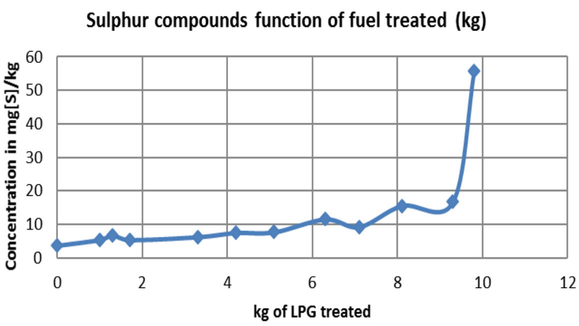
THT concentration can be extracted from the “GI-OD-12-03_D129_Odorization_and_interoperability _Final_document_09-10-12” from Marcogaz and H2S concentrations from the “GASQUAL DELIVERABLE APPROVED BY CEN/BT WG 197 GAS QUALITY" . We can then establish for the different region the expected total sulphur content. A correlation of the actual sulphur content is shown below for the country of Denmark with measurements from both Energinet and Ballard Power systems. The data base above indicate 9.81 mg[s]/nm3 while the authority indicates that the concentration between 4.17 and 10.82 mg[s]/nm3. In house measurement indicates 8.21 mg/[s]/nm3.

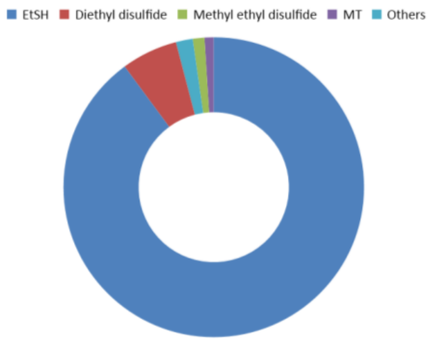
	Denmark (THT)	Denmark (H2S)	Total Sulphur compounds in mg[S]/Nm³
Reported by authority	11.00 - 19.22	0.20 - 4.10	4.17 - 10.82
Measured	18.20	1.71	8.21
Difference	1.22	0.44	2.61

In the liquid petroleum gas, 17 different sulfur compounds were detected by GC-SCD analysis and 10 of these were identified based on their retention times (Table 1). Only two compounds consistently present in the LPG, at retention times 12.41 and 18.40 min, have not yet been identified. The sulfur compound composition became increasingly complex and the concentrations generally increased as the bottle was emptied. However, the identified sulfur compounds constituted an estimated 99.0 ± 0.5% of the total sulfur concentration on average, with ethanethiol accounting for 94.4% on average.



The average sulphur content has been neasured to be around 10.3mg/kg, ethanthiol being the largest contributors. The desulphuriser will also have to be capable to deal with end of tank sulphur content which has been measured around 50mg/kg.





The regulatory according to the ISO 9162 indicates that LPG should contain less than 50mg/kg of Sulphur. The Danish regulation states that a minimum of 10 mg/kg of ethyl mercaptan is present equivalent to a minimum of 5.15 mg[S]. The specification from Nordic region LPG supplier states that 1.5 mg/kg is the residual sulphur before odorisation. This leads to a minimum total sulphur content of the 6.65 mg[S]/ kg.

	Denmark	Germany	Italy
Regulatory max	<50.00	NA	NA
Measured	10.30	NA	NA
Difference	<39.70	NA	NA

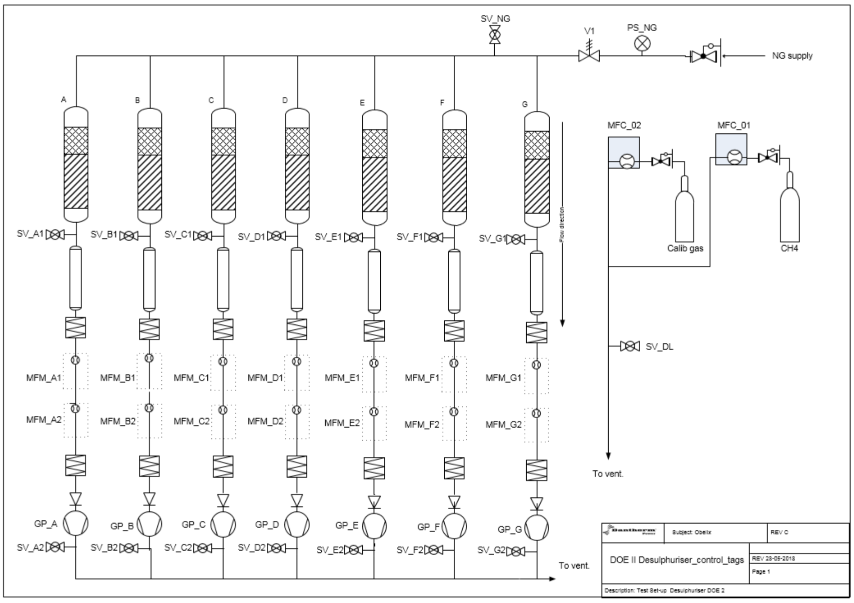
Fuel usage and determination of sulphur to be treated

The fuel consumption is assessed by the modelling performed in WP5 task A. The result can be found in Appendix 3 and 4. By correlating the fuel sulphur concentration to the fuel treated, we can determine the amount of sulphur to be removed. Since residual acceptable sulphur content is in the ppb level, we will assume that all sulphur should be removed. Results are summarized in the table below:

	Amount of fuel to be treated in 40 000 hours of operation	
Fuel type	NG (DK)	LPG (DK)
Weight (kg)	24240	25079
Energy equivalent (kWh)	326634	332766
Sulphur content mg[S]/kWh	0.89	0.80
Amount of sulphur to be treated in g	291	266

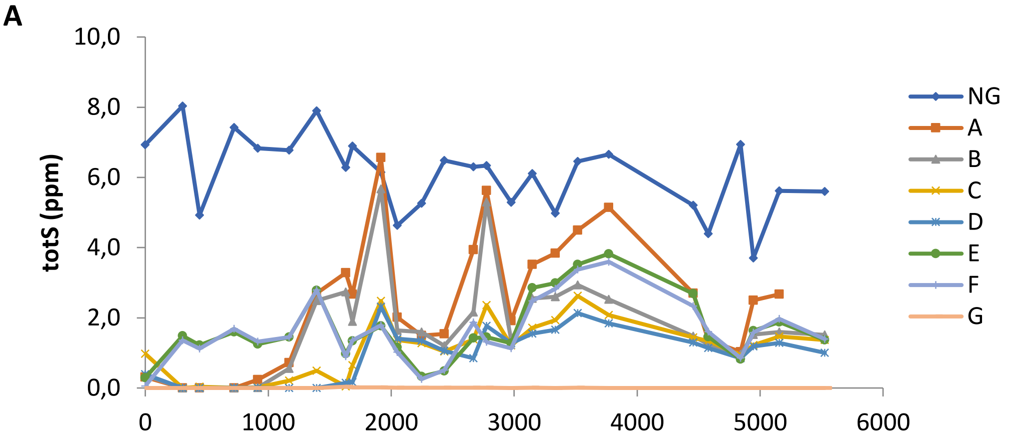
Evaluation of desulphuriser:

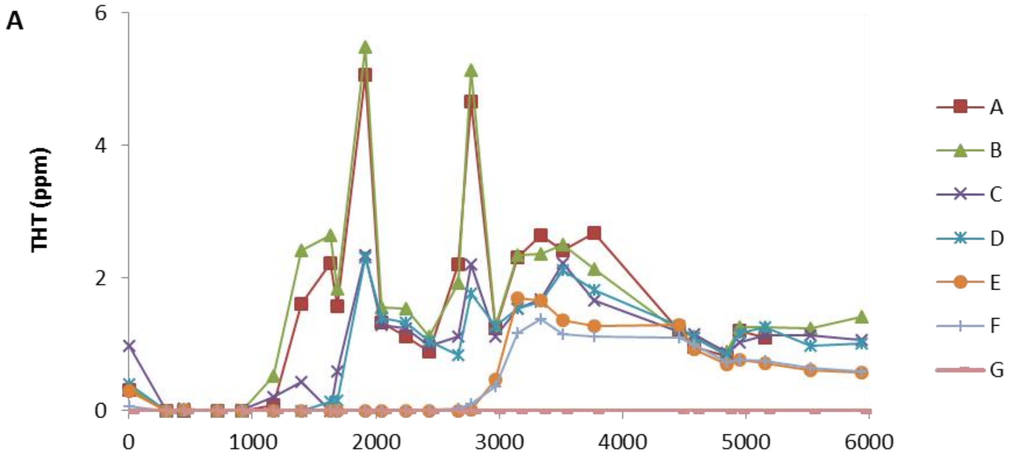
9 different adsorbents have been evaluated separtely or combined. Some adsorbents were tested for more than 9 months on Natural gas.

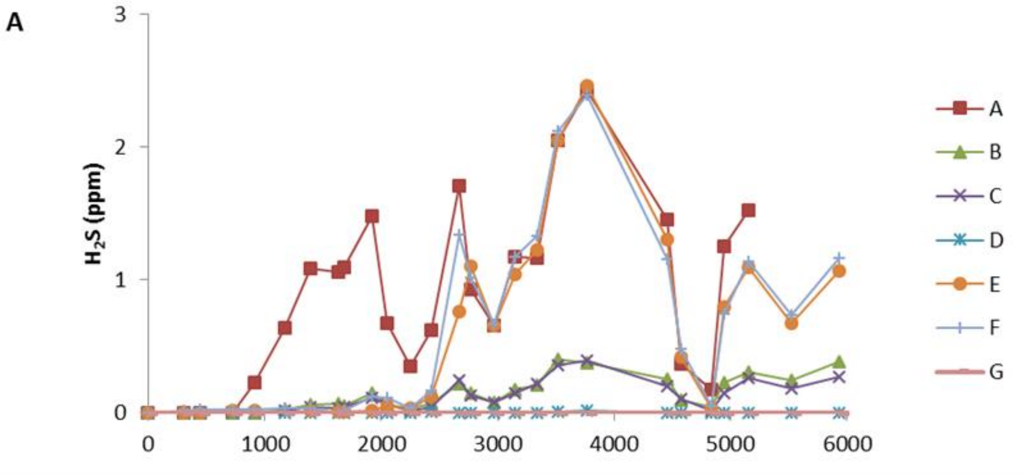


Adsorbent type	H2S	THT	THT	THT	H2S	THT	THT	THT/H2S	H2S
Material	Cu, Zn, AL, C	Mo	Zeolite, Silica	Si, Mg, Al, Fe	Cu,Si,Mg, C,Na	Zeolite	Zeolite	Ag	Cu
Specified density (kg/L)	1.30	0.95	0.63 - 0.85	0.65 - 0.75	0.94	0.60	0.66 - 0.62	0.73	0.9 - 1.3
Measured density (kg/L)	1.17	0.85	0.73	0.82		0.70	0.78		
L/D	4-6	4-6				5.0			
Space velocity h-1							9500		
Empty space velocity or LV cm/sec	27 (best), 100 (optimal)					2,5 Ok - 1 ok but lost of 5%-10% compared with 5	1-10		

The performance assessment indicates that A, B,C,D E and F had poor performance. G did not reached breakthrough after 6000 hours of operation. A separate test was made on LPG proving that G was also a suitable candidate. Absorbent G was implemented in our product.





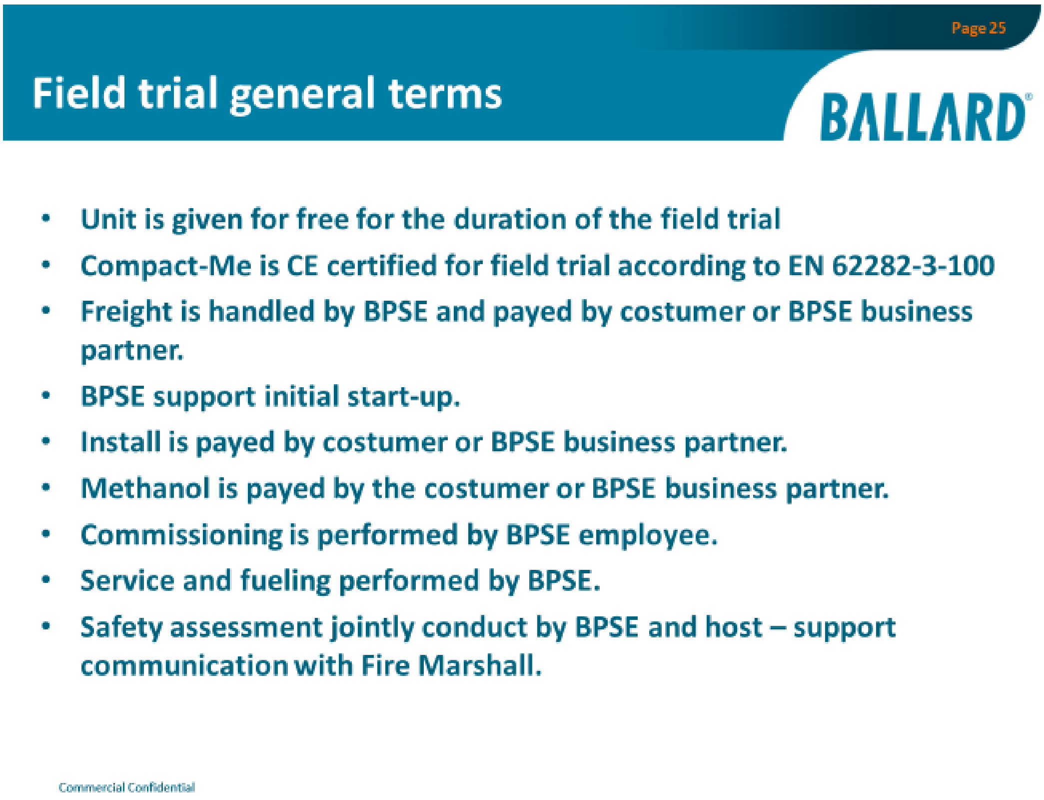


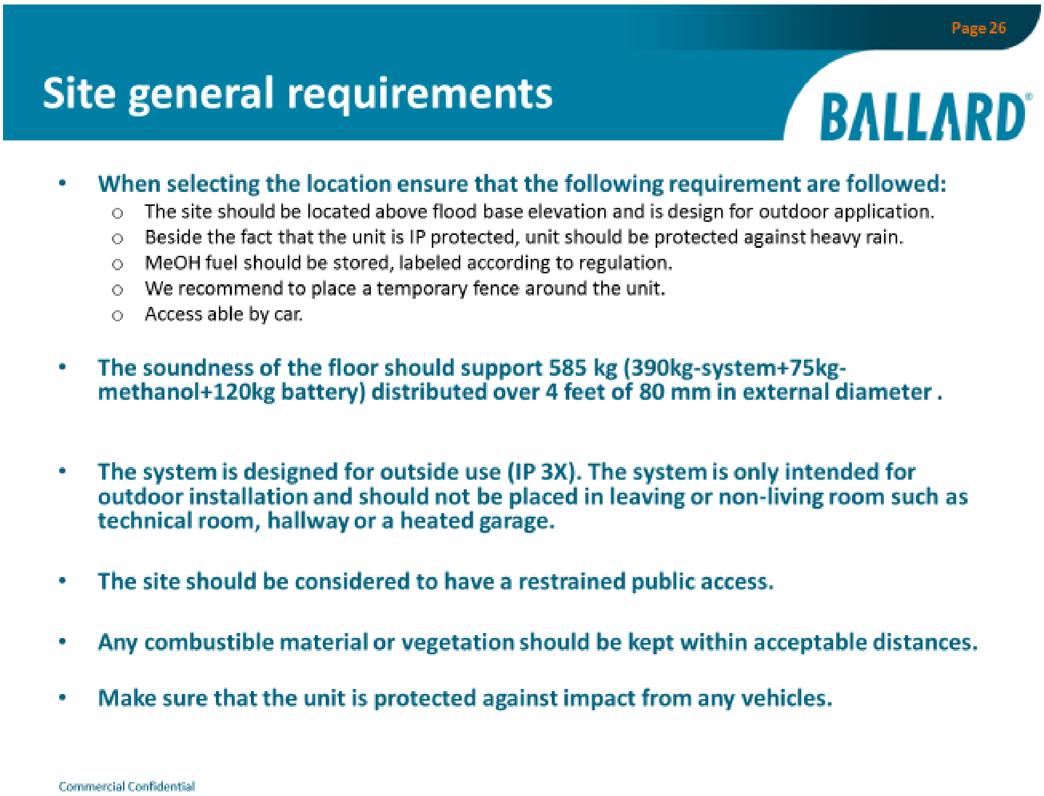
In conclusion, a comprehensive survey of sulfur in NG and LPG has been completed covering several regions of Europe (Danish, Italy, Germany, France). A robust, selective and sensitive method has been devlopped around sampling and post processing chromatogram. A Long-term qualification of desulfurizers have been completed for LPG and NG with 20000 hours of test performed on 7 commercial adsorbents beds on natural gas and LPG. Identification of best candidate and selection for field trial of G adsorbents.

1.5.3 WP 3 Definition of the field trials:

4 different field trials have been secured:

- 5 natural gas systems tested in the Enefield program.
- 1 LPG on grid for the Hobro Gas Museum with Kosan Gas as partner.
- MeOH off grid generator for festival and events planned with a Ferie center on Jegindø island.
- 1 MeOH shipped and tested in Japan at Nokia Siemens Solution.





1.5.4 WP 4 Manufacturing of the unit

Two platforms have been constructed as mention in WP1. On base on Idatech methanol reformer and Ballard air cooled 1030 stacks and one based on WS reformer and Ballard 1310 liquid cooled stacks. The units based on WS reformer was certified for household application according to the Gas appliance directive and went through a full certification process. Performance was also verified by external partners.

Laboratory test Fcgen-HC2-mCHP (BALLARD POWER SYSTEMS EUROPE)

DBI GTI Gastechnologisches Institut

Efficiencies

Average values in stationary state (power stages)

P_{el}: 2,0 kW

No.	t_{RL} in °C	t_{VL} in °C	electric efficiency	thermal efficiency	total efficiency
4	30	68	0,272	0,693	0,965
5	35	68	0,267	0,669	0,936
6	40	68	0,265	0,644	0,909

P_{el}: 1,2 kW

No.	t_{RL} in °C	t_{VL} in °C	electric efficiency	thermal efficiency	total efficiency
1	30	68	0,254	0,625	0,879
2	35	68	0,257	0,611	0,867
3	40	68	0,258	0,591	0,849

No.			t2 [min]
7	35	68	80


kiwa
Partner for progress

Number	91836/01	Replaces	--
Issued	03-06-2016	Scope	2009/142/EC (30-11-2009)
Report number	150600939	Contract number	E --
PIN	0063CQ3939		

Certificate

EC VERIFICATION CERTIFICATE (GAD)

Kiwa hereby declares that the µCHP, type

FCgen-HC2-mCHP

Serial numbers (amount): 001 up to and including 020 (20x)

manufactured by Dantherm Power A/S
Hobro, Denmark

meets the essential requirements as described in the Directive 2009/142/EC relating to appliances burning gaseous fuels, Annex II, procedure 5.

Appliance types : C13, C33, C63
Appliance categories : I2H, I2L
Countries:

Austria	France	Lithuania	Slovenia
Belgium	Germany	Luxembourg	Spain
Bulgaria	Greece	Malta	Sweden
Croatia	Hungary	Netherlands, the	Switzerland
Cyprus	Ireland	Norway	Turkey
Czech Republic	Iceland	Poland	United Kingdom
Denmark	Italy	Portugal	
Estonia	Latvia	Romania	
Finland	Liechtenstein	Slovakia	

Luc Leroy
Kiwa

Kiwa Nederland B.V.
Wilmersdorf 50
P.O. Box 137
7300 AC APELDOORN
The Netherlands
www.kiwa.com

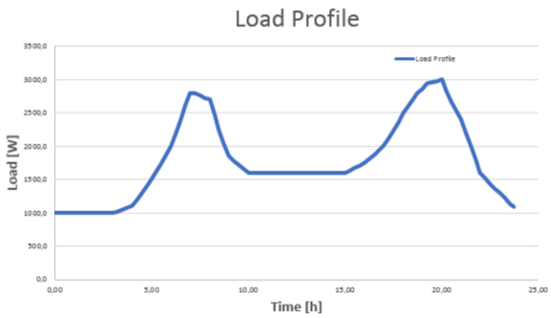
GASTEC

kiwa Approved EC Directive EC VERIFICATION 2009/142/EC GASTEC

CE 0063

Battery Charger

The hybridization study demonstrates the operation of lithium-ion battery with an LPG operated fuel cell system. The load profile was constructed to represent an off-grid household consumption or prime power for telecommunication which appear to have a very similar pattern.



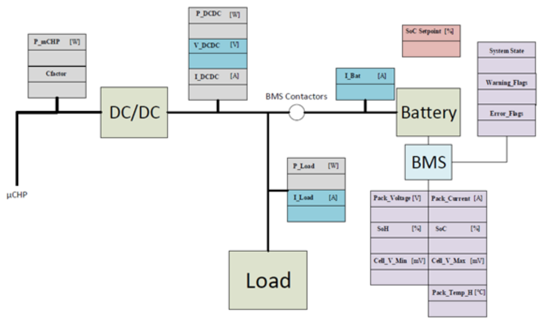
Due to the Cyclic load profile, lithium-ion batteries were chosen as the energy storage extension to the FCgen-HC2-mCHP system. LiFePO4 battery was chosen due to its advantage regarding safety and lifetime compared to other lithium-ion batteries. Utilization should be within 25-50% Depth of Discharge (DOD) for optimum lifetime. Furthermore, a Battery Management System (BMS) is required for safe operation when using Li-ion batteries. With the Load profile, electrical specifications for the mCHP and DC/DC it was possible to determine battery specifications. Electrical specification for mCHP, DC/DC and battery pack is listed in the table below.

mCHP		
Maximum production out mCHP.	[W]	2500
Minimum available production when modulating	[%]	70
Max. Load during warm-up including internal losses	[W]	150
Warm-up time	[s]	3600
Extra warm-up time - error burner	[s]	600
Consumption warm-up	[Wh]	325
Minimum production hours	[h]	24
Inclusive internal losses	[W]	**280**
Start-up time	[s]	120
Consumption start-up	[Wh]	9
Consumption before production	[Wh]	334
Maximum load change on production. From graph	[A/s]	0,05
Lowest voltage output from mCHP	[V]	18
Maximum calculated change rate	$[\Delta \frac{W}{s}]$	0,90
Maximum power ramping up/down / hour	$[\Delta \frac{W}{h} \%]$	130

DC/DC		
Efficiency DC/DC conversion	[%]	93
Maximum powerloss DC/DC conversion.	[W]	175
Load for dissipation af heat	[W]	0
Min. surplus for maintaining batt.	[W]	0
Max. Available power for consumer/charging. Supply limit	[W]	**2045**

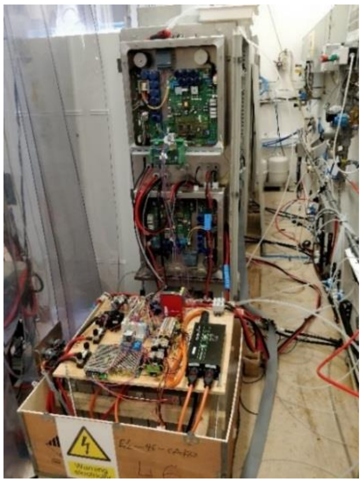
Batteries		
Number of battery cycles/24 h		2
Expectes lifetime	[year]	4,6
Ambient battery temperature	[°C]	25
Maximum DOD	[%]	50,0
Efficiency charging/discharging	[%]	98,75
Maximum current consumer	[A]	63
24 hour resulting energy level battery	[VAh]	**0**
Calculated minimum utilised capacity	[%]	50,0
Chosen maximum utilised capacity	[%]	82
Maximum expected charging voltage/battery	[V]	50
Maximum charging current - from table	[A]	23,2
Actual lowest current curve	[C/]	7,75
Lowest acceptable current curve	[C/]	2,0
Initial energylevel batterypack X percentage	[%]	56
Maximum energylevel batterypack	[VAh]	6953
Minimum energylevel batterypack	[VAh]	4336
Maximum utilized battery capasity	[%]	80,4
Minimum utilized battery capasity	[%]	50,2
Calculated battery size by maximum value	[VAh]	8479
Calculated battery size by minimum value	[VAh]	8672
Calculated battery energy	[VAh]	8640
Chosen battery pack size	[Ah]	180
Resulting expected lifetime from graph	[year]	**4,1**
Total loss charge/discharge	[Wh]	129

The test bench was designed and constructed with the purpose of adding the battery functionalities to the FCgen-HC2-mCHP system as an addon-unit. The test bench was designed and constructed with following functionalities



- Monitor energy distribution between Load module, DC/DC and battery pack
- Handle all safety functions related to the battery pack

The testing was conducted in laboratory environment at BPSE with the test bench and FCgen-HC2-mCHP placed in a ventilated test area. A controllable load module was placed to simulate the specified load profile. Following picture shows the test complete test setup.



A 72hr test with continuous operation was conducted to document the platform, the test results are illustrated in the figure below. The test product consists of 3 duty cycles leading to 6 peaks.
Fejl! Henvisningskilde ikke fundet.
The test demonstrates the system load following capability while taking the state of charge (SoC) into consideration. The maximum DoD in the tests is shown to be 26%. The DoD being 26% instead of the dimensioned 50% is related to the maximum performance of the DC/DC being ≈2250 W instead of the specified 2050 W.

During the 72hour testing period the mCHP had two shutdowns, not related to the battery extension, at 9 and 11 o'clock at 8th of February. These shutdowns resulted in the battery pack instantaneously supplying the power needed to the load. This did not result in the output load being cut off proving the power back-up capability of the architecture.

Throughout the testing period, totalizers have been collected, energy production and consumptions on various node of the system. The relevant numbers have been compiled in the figure below, which also shows the efficiencies of the system.

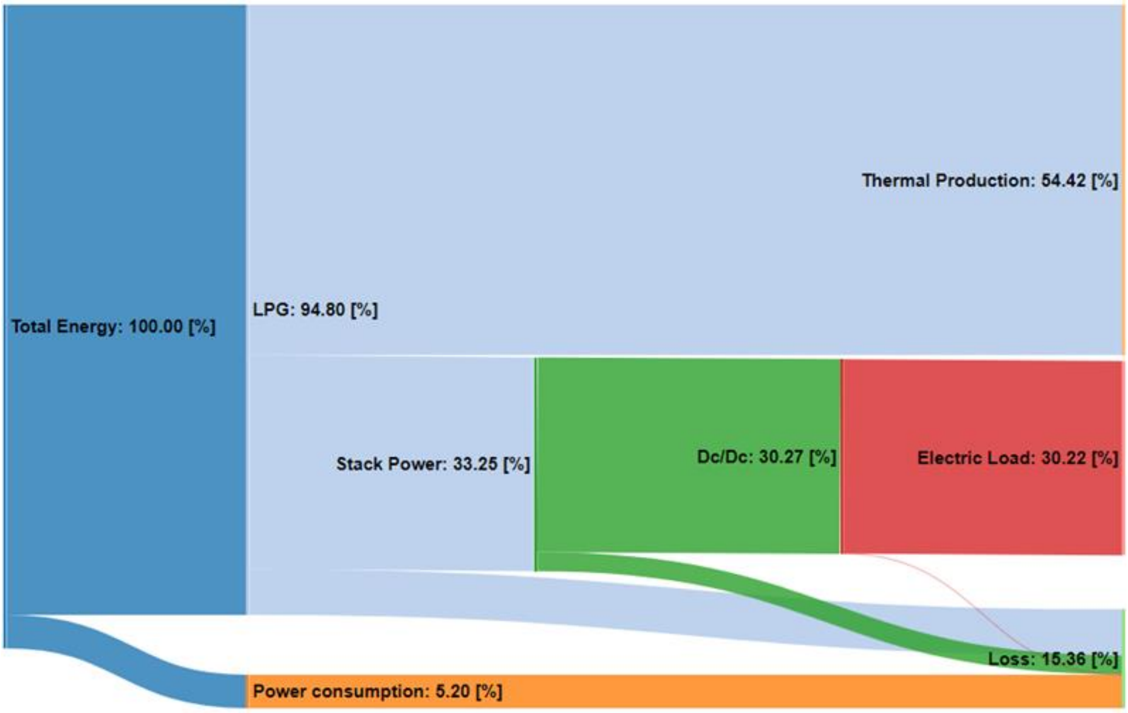
Production and efficiency			
µCHP		Energy [kWh]	Efficiency [%]
Consumption	Gas	405,600	
	Electricity	22,270	
	Total	427,870	
Production	Thermal	232,830	54,4%
	Stack	142,260	33,2%
	Dc/Dc	129,530	30,3%
Battery pack	Charge	10,230	98,9%
	Discharge	10,000	
Energy Loss	Production loss*	52,780	
	Dc/Dc	12,730	
	Battery	0,230	
	Total Loss	65,740	15,4%

* Production loss accounts for: Radiation loss, electricity for the system etc.

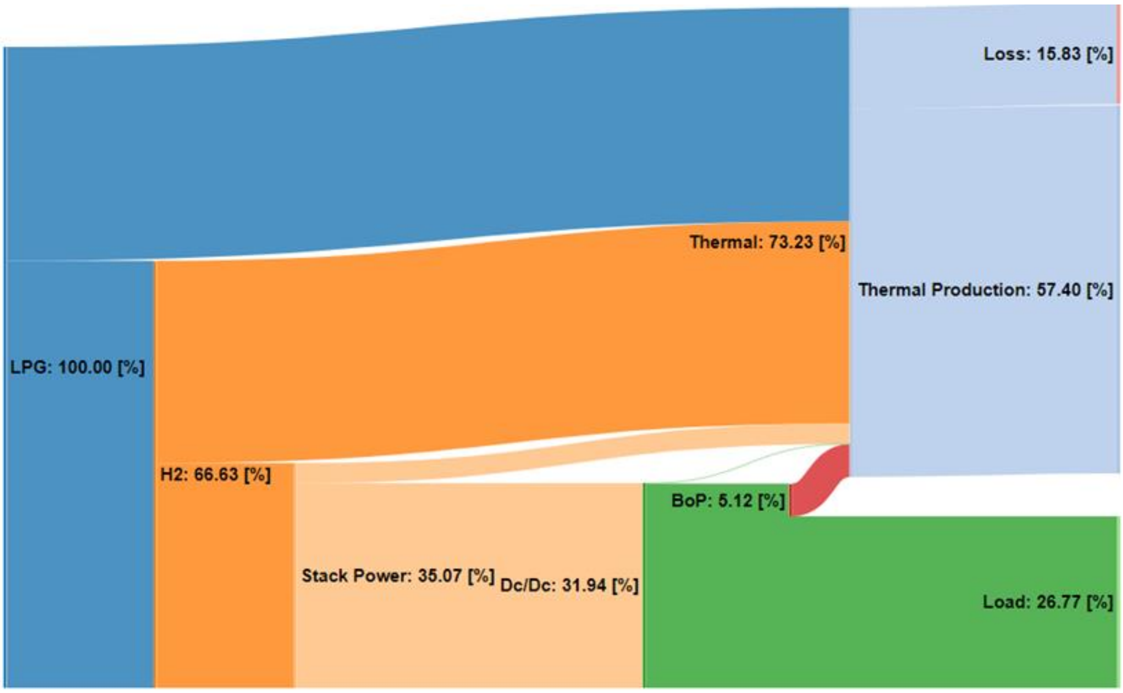
Gas calculator LPG		
Gas consumption	16,12	Nm3
	16124,96	L
	719,86	Mole
	31,67	Kg
	1460172,72	KJ
	405,60	kWh

Battery calculator		
SoCstart	79%	
SoCend	78%	
Estart	6,8256	
Eend	6,7392	kWh

A Sankey diagram was made using the numbers from the above tables, to provide an overview of the energy flow in the system, see below figure.



The diagram shows that the battery extension is operating as a grid stabilizer and with a high efficiency, which is explained in the low loss from the DC/DC. Furthermore, the diagram shows a high electrical system efficiency of 30%. The test was conducted with BoP electricity being supplied by external 230V AC (marked as Power consumption). In a microgrid solution the BoP electricity would be supplied by the platform, from the DC/DC. The following Sankey diagram, represents the energy distribution if the BoP electricity was supplied by the platform in the same test scenario. This scenario is more representative of the final product.



Using the DC/DC to provide the BoP electrical power would require the system to produce the electrical power needed which as a result will lower the overall electrical system efficiency to ≈27%.

Conclusion:

The initial test of the FCgen-HC2-mCHP with a lithium ion battery demonstrate the hybridization capability of the product by providing peak shaving and load leveling functionalities. The controller and DC/DC is capable to adapt to varying battery voltages, as well as abrupt load changes. The system can adapt to the battery SoC and act as battery charger. The test results from the 72hr continuous test shows the system being able to handle a cyclic load profile with load above and below the electrical specifications of the FCgen-HC2-mCHP system. Furthermore, the tests results shows high efficiencies throughout the test period, with a system efficiency up to 84,7% and a charge/discharge efficiency of the LiFePO4 batteries of ≈98%.The test shows the system being able to handle short shutdown periods for on the FCgen-HC2-mCHP system without any implications on the consumer/Load module, after shutdown periods the mCHP compensates for the shutdown by providing additional energy to the battery pack.
The DoD shows to be below the specified DoD, which is a result of the DC/DC converter overperforming, being able to provide 2250W instead of the specified 2050W. With a DoD being ≈26% indicates that the system would be able to operate with a lower battery capacity. The BMS with single battery cell monitoring is configured with focus on providing stability to the grid and the ability to charge and discharge to battery continuously. The BMS handles all safety functionalities needed to ensure a safe operation of the LiFePO4 batteries e.g cell balancing, temperature monitoring, current monitoring. If the batteries are being operated in a non-safe way the BMS will disconnect the battery pack from the system, through the "BMS contactors".
Throughout the testing period the system controller was supplied by 230V. This would not be the case in a off-grid solution, since the system would need the control logics being powered before being able to start. Further options could be added to address a broader segment:

- A standard sinewave inverter could be added to obtain an AC outputs.

- The current system is not able to discriminate between different consumers/loads. Implementing a discriminating functionality by adding contacts and relays gives the operator the possibility to prioritizing the consumers/loads. This would be a useful functionality in a stand-alone system to provide additional safety and stability to the microgrid.

1.5.5 WP 7 Product evaluation by end customer:

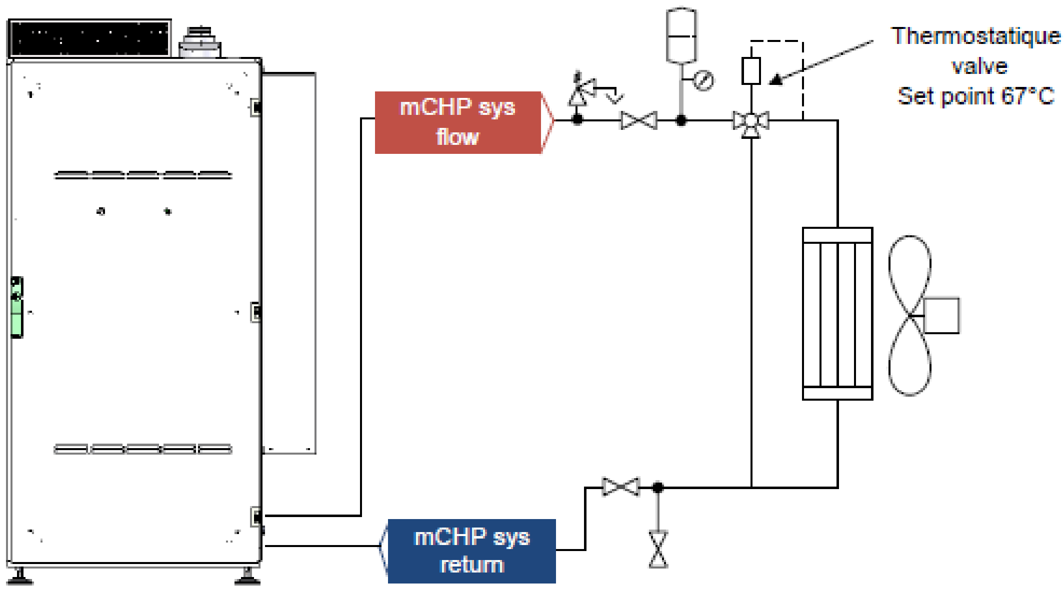
4 configurations of unit have been tested:

- FCgen - HC2 – LPG - Grid connect (Hobro gas Museum)
- FCgen - HC2 – NG - Grid connect (Internal + Enefield)
- Electragen - Me – Off grid AC (Jegindø island)
- Electragen - Me – Off grid battery charger (Nokia Siemens – Japan)

		Fuel			Electrical		
		MeOH	LPG	NG	Grid connected	OFF grid	
						Battery charger	Inverter
FCgen- HC2	Internal		✓	✓	✓	✓	
Electragen Me	Internal	✓	NA	NA		✓	✓

<u>FCgen - HC2 – LPG - Grid connect (Hobro gas Museum)</u>

During the identification process of possible test sites, BPSE contacted Kosan Gas A/since they are the main supplier of commercial LPG in Denmark. Kosan Gas accepted to be part of the project which lead to a letter of intent between BPSE and Kosan Gas. BPSE performed several site visits with the support of Kosan Gas. Hobro Gas Museum was selected as test site for the LPG field trial. The Gas museum have an existing LPG installation, which have been taken out of service after they stopped hosting a factory of glasswork. The system will be used to provide heat and power for one of the gas museums buildings. The system will operate on heat demand.

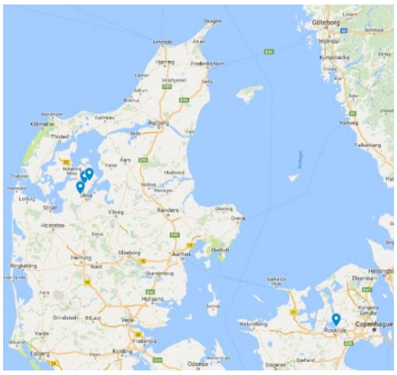


Besides providing the heat and power during the field trial, the unit will be kept as display for dissemination purposes around fuel cell. Site inspection was done in August 2017 together with installers as well as the Fire Marshall. The installation was registered to the relevant authority by the electrician and plumber. The change of system to LPG and the certification took some time and system was installed in January 2018. System is set up with MMI Multi Media Interface in-order to display online system data for any possible guests. Picture is taken just after installation with represents from Gas museum and Kosan Gas:

The FCgen-HC2 was configured for LPG operation and approved by Kiwa according to the Gas appliance directive. The system was certified for a field trial of 2 months or 200 hours – 300 start-stop. The installation of the system went very well. During the field trial 2 fault shutdowns were reported. 1 fault being a loose electrical connector for the systems cathode blower. The second fault was low condensate water level due to high return temperature from the installation. The installation was adjusted and the system operated without faults for the rest of the field trial. The system has been shut down in February 2018 where it had accumulated 314 hours of operation during the field trial.

<u>FCgen - HC2 – NG - Grid connect (Internal + Enefield)</u>

As part of the European sponsored by the Fuel Cell and Hydrogen Joint Undertaking program Engie France and Ballard Power System Europe, Denmark worked together on the installation and operation of five mCHP units installed in Denmark. The five FCgen-HC2-mCHP units have been successfully installed in 2 areas in Denmark. In the heating season 2016/2017 more than 17.000 hours of operation was registered, with an average availability > 70 %. Among the main challenges faced were: 1) Some instances with a high temperature of the return cooling water, 2) Missing data on the external monitoring of the electric output, 3) Continuous contamination from fuel processing plant, 4) Modification of cathode air supply and subsequent exhaust path, 4) Reduced electrical efficiency

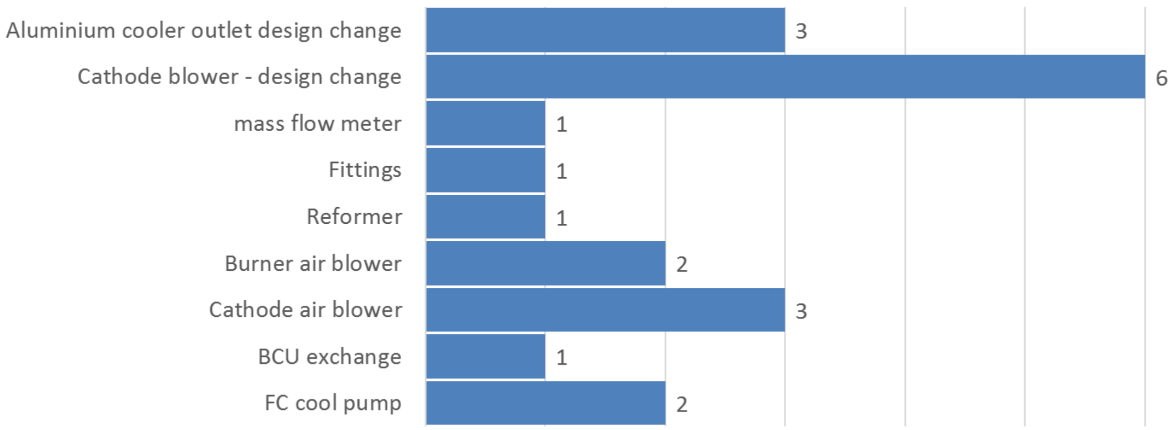
 

4 installation sites were selected among consumers in the municipality of Skive in the north-western part of Jutland, and the Technical University of Denmark, DTU near Copenhagen. The selection is based on readiness and accessibility of the installations, as well as a base consumption of heat and electricity large enough to ensure utilisation within the installation entity. Among the 4 sites originally selected in Skive 1 had to be cancelled, as it was not feasible to be installed in the electrics, due to already installed solar panels and their settlement rules set out by the electricity utility company. As it turned out there was room for 2 units on one of the other sites. The 5 FCgen-HC2-mCHP units conscripted for deployment in the Enefield field trial were delivered to the installation sites during September 2016 and installed during October 2017. The 5th unit was offered to the Technical University of Denmark, DTU, an internationally recognised university, with research and educational facilities in Lyngby, Ballerup and Risø, on the Island of Zealand. The offered installation site was at the Risø campus, where there is a strong focus on energy technologies.

System ID	001	003	004	005	006
Enefield	2277	3255	4330	3477	4172
Durability Sum	3127	7830	5522	5384	5385
Op. Cycles	235	313	84	163	69
Durability comment	Enefield concluded	Reformer development	Enefield concluded	Aluminum corrosion	DTU display

System ID	000	002	007	008	Sum
Durability Sum	4495	4481	5085	2208	43269
Op. Cycles	407	328	214	71	1884
Durability comment	LPG/Battery	D2Service	D2Service	LPG Demonstration	

During the duration of the field trial 20 components were exchanged, repaired or modified in total.



Component repairs	Failure / modification description	Counts
Fuel cell stack cooling pump	Rotor bearing was worn out, giving too much clearance to the shaft, causing noise and pump house abrasion. Rotor was changed, and motor housing kept. Same motor had the rotor exchanged twice, could be a system specific issue.	2
Burner Control Unit exchange	The electronics of the burner control unit was damaged	1
Cathode air blower	Some versions of the newly developed cathode air pump could not deliver the specified air flow.	3
Burner air blower	In several incidents, the burner air pump was worn out. Seems that the pump bearings are failing prematurely.	2
Reformer	System DAN0205 had a small leak in the reformer, found during the Site Acceptance Test. Needed re-brazing.	1
Fittings	1 cooling water stud was found cracked	1
mass flow meter	1 mas flow meter was found malfunctioning due to moisture from a back flow of water.	1
Components design change		
Cathode blower	As the development of the cathode air pump continued, an exchange program was conducted.	6
Aluminium cooler outlet	The main reason for the safety chain cut out was traced to the manifold of the exhaust gas heat exchanger, or Co-gen. Therefore, a modification program was initiated. The program was not completed at the reporting date.	3

The combination of the field trial associated with the preliminary durability test led to the following observations and potential improvements:

- Difficulties to obtain grid approval from the utility company indicates that a contract with the grid utility should be established at a very early stage and supported by the authority in some form of regulatory program to ensure an appropriate level of commitment from the grid operators.
- Despite a thorough product installation training of the installers combined with a detailed screening of each site, we observed that some sites could not handle the heat produced due to the elevated level of the return temperature. For example, operation with a wood pellets boiler requires the FCgen-mCHP-HC2 to handle high return temperature (>60°C) which is not possible with the current product revision. Furthermore, education and training will be needed to ensure an effective thermal coupling to other heat sources.
- We have gained valuable experience on the core platform by demonstrating more than 17 000 hours of runtime on which an extra 18 000 hours can be added from the testing performed internally prior to the deployment of the appliances. Core technology improvement primarily on the reformer side which has led to the design of new catalyst for the reformer. The original catalyst of the reformer caused some stack performance decay as well as accelerated corrosion process leading to premature failure of our ions exchange resin beds and heat exchange. The burner control board is not suited for the FLOX burner technology (WS reformer burner technology) and that both safety and burner controller require one new iteration to reduce burner lambda from 1.9 to 1.1 which will allow to increase the allowable hot water return temperature from 45°C to 50°C. Water separation on water heat exchanger manifold should be redesigned to

reduce pressure drop. Rotary vane blower selected for this platform should be redesigned if conserving actual stack design. Noise and thermal emission need to be lowered. Burner air pump also shows sign of premature failures.

- The controllability of the machine can be improved by adding the following functions: Safety chain need to be more intelligent. For example, flow deviation leads to an emergency shut down which lead to a temporally overheating of the coolant water circuit. To accommodate scenario of repeated re-start, position of the level sensor on the process water tank height should be relocated to allow for additional process water capacity.
- The energy metering system implemented is difficult to configured and the metering hardware should be prequalified prior to be implemented. Alternatively, it will be possible to rely on internal information generated by the appliances but require acceptance of the from the trial end-user.
- The FCgen-HC2-mCHP required one more iteration go from "Concept" to "Pre-commercial" production.

The business model adopted for the ROE is based on a direct used of the produced electricity and heat on site. We assumed that the produced electricity offset the customer electrical bills and the heat generated reduces the consumption of the natural gas from the boiler. We assumed that the installation still contains a boiler for supplemental thermal power. The ROE is based on a simplified linear amortisement payback period calculation (without depreciation and inflation). The model accounts for:

- Electricity price and natural gas price based on 2017 invoices (household prices)
- Electrical efficiency of 25.1% based on measured data from DBI GTI (measured data from DBI de-rated for middle of life performance lost)
- Thermal efficiency of 66 % based on heating water return temperature of 40°C
- Opex including material cost based on field trial and service hours
- 4000 hours heating season
- Installation and installer margin €4032
- Boiler efficiency of 105%
- The electrical energy is consumed on the site (no grid feedback and no feed in tariff)

FGgen_HC2_mCHP		Danmenark business case - qty 3000
		Comment
Gas price (incl tax -€/Nm3)	0.810	
LHV (kWh/Nm3)	10.95	77GJ - Total yearly consumption by mCHP
Gas price (incl tax - €/kWh)	0.074	
Fuel consumption total (Nm3/h)	0.49	
Electric power output (kW)	2.04	
Thermal power output	2.85	91% total efficiency at 40°C return temperature
Cost of electricity (€/kWh)	0.242	
Appliance eklectrical efficiency (LHV)	38.0%	MOL efficiency
Service cost (material)	1.19	€ cents /kWh_elec
Flow rate in NLPM (0C-1 atm)	8.17	
Heating season (hours)	4000	
Electricity produced (kWh)	8160	
Electricity produced (€)	1975	Electricity end-user do not have to buy - Electricity consumed on-site
Heat produced (kWh)	11381	
Thermal efficiency Boiler	105%	Efficiency achieved by condensing boiler
Fuel consumption heating (Nm3/h)	0.25	Expecting cumsumption by boiler
Heat produced by boiler (€)	802	
Total fuel cost CHP (€ per 4000 hours)	1589	
Total fuel cost CHP+ service (€ per 4000 hours)	1686	Service include 2 hours of labor
Saving (€ per 4000 hours)	1091	
Machine price at qty level 3000 (€/machine)	17780	
Installation + installer margin cost (€)	4032	
Installer Margin	1.23	
Pay back in years	20.0	

MeOH field trial – Off grid application 230 VAC

The identification of test site in Denmark to demonstrate a methanol system was initiated. The market segment of portable generators was targeted and numerous organizations and festivals have been contacted to find an appropriate test site for ~200 hours of field test. Several field trial options were investigated with Ok Amba but could find a suitable solution.

Commercial effort done internally led to the identification of Jegindø camp. It was selected as a test site, due to the available space, duration and the dissemination perspective with the possibility of having news coverage by the regional TV news and the local paper as well.

Ballard Power Systems Europe BPSE agreed with the end user that BPSE could do the installation without any site inspection if the local authorities accepted the field trial prior to installation. BPSE contacted the local fire Marshall and they were okay with the scope of the field trial. The 2 systems where installed outside at Jegindø camp. Everything was protected against the public by a fence with warning signs. The systems have an integrated fuel tank. Fuel was located on site in an 800L. IBS container. Refueling was handled by BPSE technician during the field trial. The fuel is premixed methanol /water 61,8/38,2 WW%. The two systems are used to power outside lighting and the lighting inside a tent by the means of 1 SMA sunny island inverter pr. system. Picture of the site installation:

During the FAT Factory acceptance test the fuel consumption has been verified based on the systems internal fuel gauge and the tank size being 75L. According to the datasheet the fuel consumption is 1,4L/kWh. And therefore, it is possible to operate the system for 2 full days at 2kW load without refueling. The fuel level reads 37% and it took ~11,5h. to empty the tank. The produced electricity corresponds to ~23kWh. Table with the result:

Area gauge (%)	Estimated (L)	Real (based on fuel gauge) (L)
37-25	18,2	9
25-0	14	18,75

The fuel gauge showed to be very inaccurate and to use it to calculate the time left for refu-eling is not an option. The consumption based on the fuel gauge showed to be 1,2L/kWh. The systems FAT test showed that the system could operate with a continuous net power of 2kW. The systems operated throughout the field trial with a load of ~400W pr. system which was lower than expected. Systems where almost 100% operative during the hole field trial. Only one system fault shutdown was reported but could also be related to the external installation. The systems produced a total of 146kWh which corresponds to ~208 hours of operation pr. system at a load of 400W per system.

<u>Electragen - Me – Off grid battery charger (Nokia Siemens – Japan)</u>

The field trial in Japan was made in partnership with Nokia Siemens and Domoco. The unit was installed and operate for more than 200 hours. A feedback was provided regarding the optimization which be taken into account for next iteration.

Docomo fully understood that product is proto-type and purpose to gather the feedback, comment and recommendation for better commercial product.
Here are the following feedback';
- Design is not installer and maintenance friendly.
- height can reduce to 1.8m
- Reduce the size of controller panel to accommodate the space for 1U for solar charger unit
- Provision or termination interface point for solar device, DoCoMo future plan to have a green site solution.
    Meaning they plan to integrated compact EGME with solar energy, during daytime the supply via solar and at night batteries and fuel cell.
- re-design the battery compartment to accommodate compact Li-ion battery, instead of lead acid batteries.
- Provision for external tank, that require less modification.

10 © Nokia Solutions and Networks 2014
<Change information classification in footer>
NOKIA

1.5.6 WP 8 Optimization of the units:

<u>The following optimization have been made on the Fcgen-HC2:</u>

- Designed initially in low cost aluminum, it has been redesigned temporally to stainless steel to accommodate poor quality of selective methanation catalyst. one more iteration of the reformer is required in order cost optimized the heating loop but heat exchanger have trial and performance proven.
- Implementation of polymeric tubing for all tubing compatible in terms of pressure, temperature and media composition.
- Optimization of the power conversion module by eliminating DC/DC conversion.
- Fuel cell stack module: A new 200cm2 stack has been developed which offer lower pressure drop. A blower has been optimized for this stack. The humidifier size has been reduce by 50%.

<u>Further optimization can be made on the next generation:</u>
A proved field trial level of electric efficiency of 25 % is not satisfactory and misaligned with the initial prospect of the project. The reason for the low efficiency has been identified and will be corrected in the next revision of the machine.

- Steam to carbon: The water to gas ratio injected into the reformation process is above the levels in the industry, and needs to be revisited and tested to gain confidence in close corporation with the reformer manufacturer. The first steps and experiences have been made, and suggest that the water can be reduced by 25 %, and thereby reducing the energy needed for evaporation, and thus raising the electric efficiency more than 2.6 % points.

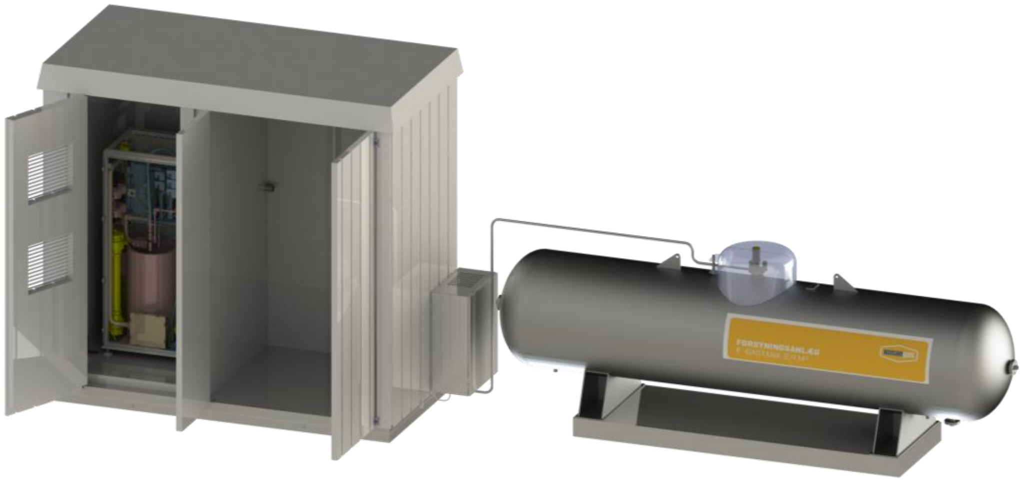
- Electric power conversion: Despite much effort, a one-step conversion from the fuel cell to the grid was not implemented in the units deployed in the field trial. In the industry, a 95 % efficiency has been obtained of power conversion from e.g. solar panels to grid. This is quite far from the 85 % realized in the current platform. This leads to a net gain in efficiency of 4.9%.
- Efforts are needed in the Balance of plant components or architecture. The system has a self-consumption of more than 10 % of the produced energy. This is not satisfactory. A reduction of 15% of the BOP can be achieved which leads to an increase in electrical efficiency of 0.7%.
- The current lambda (air / fuel ratio) on the burner air is set to 1.8. This could be reduced to 1.1 by implementing some of the controls implemented on the previous platform resulting in a gain of electrical efficiency of 0.7%. This is also allowing to increase the water return temperature from 45°C to 50°C and still comply with the process water neutrality.
- Stack performance. The adopted stack platform contains 38 cells. With an increase of 8 cells, 1.7 % of efficiency is gained.
- The heat radiation of the components has been minimized by insulation. Since one of heat exchanger is operating as a condensing boiler, harvesting the latent heat in the exhaust is critical to achieve a total efficiency nearer 100 % but will be constraints by the heating water return temperature.

	Actual	Potential	Gain in electrical efficiency
S/C (unitless)	3	4	+2.6%
Electric Power conversion (%)	85%	95 %	+4.9 %
BOP reduction (W)	250	208	+0.7%
Burner Lambda (unitless)	1.8	1.1	+0.7% /gain in return temperature of 5°C
Cell count (unitless)	38	46	+1.7%
Total	27.2%	37.8%	+10.6%

<u>Integration study – winterization optimization:</u>

The winterization study is made around a starndard transportable IP 54 rating preiss shelter and offer a 2 kW load. 2 configurations have been evaluated one with LPG and an other one with hydrogen. The LPG solution is design for continuous power while the H2 solution for short duration back-up power. 1800 hours can be achieved between 2 refuelling with LPG and 22 hours with the hydrogen fed solution. Both solutions relies on stay warm strategy during standby, the LPG using the reformer burner (i.e off grid) and the H2 solution utilized the grid power.

- Dual compartment (generator side + radio equipment side).
- 2500 L tank – 1000 kg - 1800 hours of run time.
- Heat rejection done on radiators place on the back side of the unit.
- Used of the fuel processor burner for stand-by sub-zero operation.
- 48 V- 120 Ah battery required for start-up operation in off-grid configuration.



- Modular Preiss Telecom shelter (2,5 tons).
- Dual compartment (generator side + gas storage)- Radio equipment stored in a separate unit.
- 12 T 50 cylinder – 200 bar(g) – 9.81 kg -13.5 hours of back-up power at 10 kW
- Extra 60% of Back up time can be achieved using 300 bar(g) bottle -22.2 hours
- Heat rejection done on radiators place on the back side of the unit.
- AC grid used from freeze protection
- 48 V- supercap from bridge power.

1.6 Utilization of project results

A complete study of the reactants can be used for improving design and serviceability of the Electragen and FCgen-HC2. The extended field trial combined with all designed of experiments can also contribute to improve others application.

- Improvement and utilized field trial method to other projects and products
- Hybrisation and integration of lithium ion battery to all relevant product
- Apply winterization proof concept to all stationary products,

Business Development has promoted the activity to all partners and customers using power back-up unit.

- Dedicated meeting with fuel provider (OK amba, Kosan Gas).

- Large exposure via the Enefield Field trial.
- Utilize all learnings on BPSE's back-up product platform.
- Continue commercial effort to seek for partners for the next phase of industrialization.

Secure platform for high added value market i.e. generator for Pipeline corrosion protection.

Transfer all technology learning to motive, back-up and adjacent market:
- Integrate all acquired learnings of liquid cooled stack into cross-over application such as automotive.
- Utilization of testing, system simulations, field experience data processing method for other markets such as Back-up and automotive.

1.7 Project conclusion and perspective

This project led to the development of a complete turn key versatile generator solution which can be fed with various commercial fuels. The electrical interface can be declined in 3 different configurations covering all market demand. More than 47 000 hours of field trials has been cumulated hours proving some high potential of the technology. Some technology maturity is still required to proven to address the supplemtal market. Winterization need to be proven prior to deploy such a product platform in cold climate region. Cost reduction shown in USDAN some significant opportunity with the possibility of tooling stack and performing additional design for manufacturing effort.

While continuing seeking for commercial and industrial partners, it is rather clear that the mCHP business case in not favorable with the current electricity price. Focus should be on transferring know-how of liquid cooled PEM towards motive and adjacent markets (Light, Medium and heavy duty vehicles, Maritimes).