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RES-FC Market
WP4
Deliverable 4.3
»Reports from each of 10 regional markets«

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1. INTRODUCTION

From WP 4.2 we have the general conclusion that FCHS currently are too expensive and that scale of production is necessary in order to get the price down. However, that significant cost reductions can be achieved by getting volume of production (and thereby by aggregated purchase) has been proved - and can be viewed in the cost curves provided by Dantherm. This was none the less expected as cost reduction by volume production was one of the tasks this WP was to address.

However, as it was also emphasised in the conclusion of WP4.2 that what is important, is not the cost of the FCHS, but the cost per kWh heat and kWh electricity for the consumer delivered by this system, and this cost include, not only the fuel cells in the household, but the cost of the constructing and operating the entire system. Therefore in the pursuit of obtaining cost reductions we will have to continue our work at a systems level taking into consideration prices of the hydrogen carriers, reformer units, optimization of energy efficiency of the systems and other factors that are likely to improve the possibilities of an early as possible commercialisation of these technologies.

The way that has been chosen to deal with this task is first to do FCHS cost calculations and systems optimization on the various primary fuels on a regional level. This is the primary aim of the first part of the report 4.3.

In the following 4.1 the plan was then to take the best regional solutions identified in 4.3 to the potential suppliers of the systems and go through a simulated tender procedure.

Regarding FCHS technology then most suppliers of µCHP FC-systems has proved reluctant and not yet ready to provide specific information on current or expected future prices, lifetime issues not to mention product warranty or other terms of delivery, without us having a concrete and proven intent of purchase. Therefore we had to choose a different approach to the task at hand. When FCHS have been tested and demonstrated in a larger scale and the products are closer to a real market, these factors will of course become publicly available and vital parameters of competition among the suppliers. In the ongoing demonstration projects delivery terms are agreed on at a case by case basis and the companies involved do not yet want to disseminate concrete information on the subject.

In our consortium we have two of the leading European suppliers of FCHS, who are willing to disseminate their knowledge from systems in the field.

More concretely they will provide their input with regards to how they can optimize and make the FCHS solution flexible enough to become applicable across different fuels and climate zones. They then estimate the cost at which they expect to be able to deliver this solution - and finally the cost estimates for an aggregated market including the optimized systems design, are used as a basis for a set of new cost calculations on a regional level. In this way we can see exactly how much the economy of operating these systems is likely to improve by systems optimization and the development of an aggregated market.

2. INTRODUCTION TO THE 3 DANISH FCHS SCENARIOS

By Claus Torbensen, HIRC

Even though 3 different Danish RES FCHS routes (primary fuels) are investigated in this report a lot of the assumptions, figures and facts are similar across the systems and hydrogen carriers. Therefore it has been chosen to make a joint introduction covering all 3 scenarios.

In wp2 and wp3 the identified 4 planned demonstration markets in Denmark is 421 units to be built in the coming years. Of these units 371 units is likely to be PEM FCHS which is under investigation in this study.

Location				Herning	H2PIA, Herning	Nakskov	Nolsoy	Total
				H2College				
Total size of project/ households				16	200	100	105	421
FC-technology								
PEM total				16	200	50?		216-371
HT PEM				16		25?		16-371
LT PEM				0		25?		0-355
SOFC				0	0	50?		50?
Electricity consumption/household) kWh/year)				1800	1800	?	?	
						?	?	
Heat consumption/ household (kWh/year)				1500	1500	?	?	
						?		
Hot water consumption(kWh/year)				3500	3500	?	?	

Table 1: Domestic heat and electricity demand/dwelling.

2.1. The passive house scenario

For the later calculations and evaluations upon the economy in building and operating these systems now and in the future, the heat and electricity needs of 4 persons living in a 100 m2 passive house is used as a reference. The heat and electricity needs of a Danish passive household can be seen in table 2:

Size of one house: 100 m2			Average
	kWh/m2 year	kWh/year	kWh/day
Room heating and ventilation kWh/m2 year	15	1500	4,1
Domestic hot water kWh/m2 year	35	3500	9,6
Total Heat consumption kWh/year	50	5000	13,7
Electricity consumption kWh/m2	18	1800	4,9
Total	68	6800	18,6

Table 2: Heat and electricity needs of the passive household

2.2. What is a passive house?

The passive house concept comprises a building with an extremely low energy need for space heating (less than 15 kWh/m²/year). That means that for instance a 100 m² apartment needs no more than the equivalent of 150 litres of oil or 150 m³ of natural gas per year (not including domestic hot water).

Key elements are a high thermal insulation of the building envelope (walls, windows etc.), air tightness of the envelope and heat recovery in the ventilation system.

Compared to buildings fulfilling the Danish national building codes, energy savings of 90% for space heating are achieved. But passive house is not only about energy saving – as measurements in hundreds passive houses show, both thermal comfort and air quality are much higher than in "normal" houses. Since 1991, more than 8.000 passive houses have been realized in many European countries, the majority in Germany and Austria.

As of now only a few passive houses have been build in Denmark. The interest and awareness of the concept is however very much increasing. The first construction companies have recently started supplying type houses build according to passive standard, and no doubt more will follow in the nearby future. The construction companies expect to build according to stricter building codes (with regards to energy) in the future, and in combination increasing environmental conscience among the consumers the market for low energy houses (including passive houses) is likely to be very large in the future.

2.3. Passive houses; not only new buildings

In the past few years, passive house principles and components have been successfully introduced in the retrofitting of existing buildings. Depending on the building type, energy savings vary between 80 to 95%. The specific heating demand is typically reduced from values between 150 and 280 kWh/m²a to less than 30 kWh/m²a. In some cases, the passive house standard of 15 kWh/m²a is reached. As pilot projects in different countries demonstrate, these passive house retrofit (phr) are economically feasible for a range of building types[1].

Out of the 421 RES FCHS units to be implemented in Denmark in the nearby future, more than half of them are surely to be placed in passive houses. Since it is also becoming economically feasible to retrofit existing houses to close to passive house standard surely an increasing fraction of our dwellings will be low energy houses in the future. Therefore it is logical to base our calculations upon the characteristics and energy consumption of a passive house.

2.4. Electricity consumption

As it can be seen in table below the passive house hold also has relatively low electricity consumption – only 1800 kWh year. This is less than half of the consumption of the average Danish 4 person household – but if you use the newest and most energy efficient products on the market, the energy saving can be achieved without lowering the living standard. The products in the passive house and their energy consumption can be viewed in Appendix 1.

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1 http://www.energieinstitut.at

Month	Hours	Max operation hours Wind	Max operation hours Gas,methanol	Distribution Electricity	Heating
January	744	496	744	0,09	0,14
February	672	448	672	0,09	0,13
March	744	496	744	0,09	0,11
April	720	480	720	0,08	0,09
May	744	496	744	0,08	0,06
June	720	480	720	0,07	0,04
July	744	496	744	0,07	0,03
August	744	496	744	0,08	0,03
September	720	480	720	0,08	0,05
October	744	496	744	0,08	0,08
November	720	480	720	0,09	0,11
December	744	496	744	0,09	0,13
sum	8760	8760	8760	1	1

Table 3: Distribution of electricity and heat consumption during the year.

As it can be seen in the above table the consumption of electricity and heat is not constant during the year. This is relevant because the fuel cell is to be able to fulfil the energy needs of the household on an annual basis, and with these figures we can establish a picture of how the electricity import and export with the grid will be during the year.

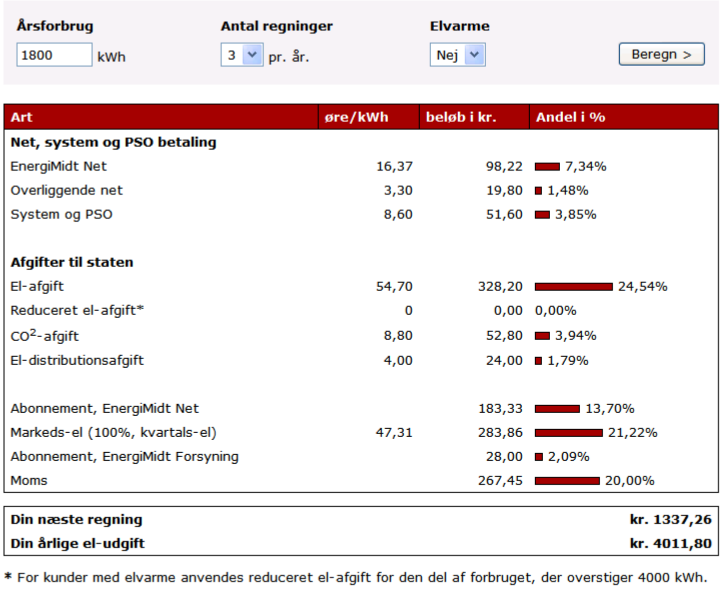
Already before having done the calculations we can anticipate that we need to use a larger fuel cell system for the wind-H2 fuelled FCHS than in the biogas and methanol cases. This is due to the fact that the biogas (NG) and methanol fuelled systems can operate 24 hours a day – while the FCHS in the wind case is closed down when the electrolyser is producing H2 and the household's energy needs in this period is supplied by grid electricity.

2.5. Control strategy

When discussing the performance of the energy system it is very important to note that the point of reference, when deciding whether or not to use hydrogen and run the fuel cell, is the heating requirement/possibility of heat storage. This is the case because the overall energy efficiency of the system becomes to low and thus uneconomically, if we don't use the heat generated from the fuel cells. The heat production from the fuel cells, can be stored in hot water tanks and directly used for hot water consumption and heating of the household via a ventilation system.

2.6. Heat and electricity prices in DK

As reference prices for electricity in DK we use a price of 2 DKK/kWh equaling 0,27 euro. The table shows the annual electricity bill for an annual consumption of 1800 kWh. From the total amount of kr. 4011 we subtract the annual subscriptions and fees we are likely to pay in our FCHS's due to our use of the grid for electricity exchange. This gives us an electricity price of roughly 0,27 euro/kWh which we use as means of comparison.



Årsforbrug	Antal regninger	Elvarme	
1800 kWh	3 pr. år.	Nej	Beregn >

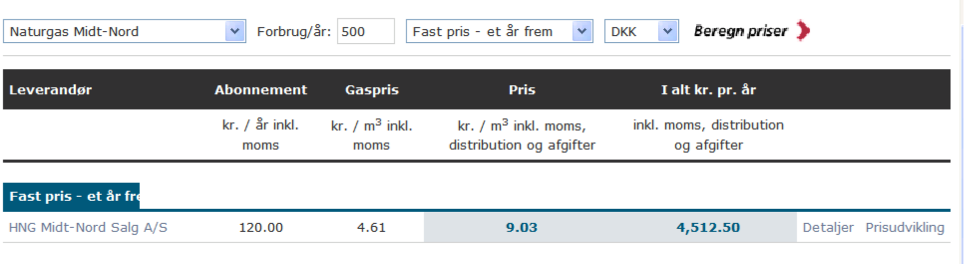
Art	øre/kWh	beløb i kr.	Andel i %
Net, system og PSO betaling			
EnergiMidt Net	16,37	98,22	7,34%
Overliggende net	3,30	19,80	1,48%
System og PSO	8,60	51,60	3,85%
Afgifter til staten			
El-afgift	54,70	328,20	24,54%
Reduceret el-afgift*	0	0,00	0,00%
CO^{2}-afgift	8,80	52,80	3,94%
El-distributionsafgift	4,00	24,00	1,79%
Abonnement, EnergiMidt Net		183,33	13,70%
Markeds-el (100%, kvartals-el)	47,31	283,86	21,22%
Abonnement, EnergiMidt Forsyning		28,00	2,09%
Moms		267,45	20,00%

Din næste regning	**kr. 1337,26**
Din årlige el-udgift	**kr. 4011,80**

* For kunder med elvarme anvendes reduceret el-afgift for den del af forbruget, der overstiger 4000 kWh.

Figure 1: Electricity prices west Danish household
www.energimidt.dk

As a reference price for heat we use 1 DKK equaling 0,135 euro/kWh. This price is calculated from the price of traditional NG heating. 1 M3 NG cost approximately 9 DKK which equals a kWh price of approximately 1 kr/kWh = 0,135 euro - including depreciation of the NG boiler.



Naturgas Midt-Nord	Forbrug/år: 500	Fast pris - et år frem	DKK	Beregn priser

Leverandør	Abonnement	Gaspris	Pris	I alt kr. pr. år	
	kr. / år inkl. moms	kr. / m^3 inkl. moms	kr. / m^3 inkl. moms, distribution og afgifter	inkl. moms, distribution og afgifter	
Fast pris - et år fr					
HNG Midt-Nord Salg A/S	120.00	4.61	9.03	4,512.50	Detaljer Prisudvikling

Figure 2: Heat prices Denmark West; natural gas.
www.naturgasmidtnord.dk

3. CALCULATIONS ON ISOLATED REGIONAL PROJECTS – WIND/H2 DENMARK

by Claus Torbensen, HIRC

3.1. Introduction/background

In this chapter, economical calculations of the use of a FCHS using hydrogen produced by electrolysis will be presented and commented upon. The calculations initially are made based upon the setup described in the previous joint introduction for the 3 Danish FCHS scenarios, WP4.2 and WP3. This implies that we for our economical calculations use a passive house scenario, we purchase of off peak heavy process electricity for the electrolyser, we calculate without heat production tariffs and operate the FCHS under a similar arrangement as the current solar power legislation in DK.

In WP3 it was emphasized that Denmark has an overall strategy for hydrogen and fuel cells. The plan/strategy is however not very specific and does not concretize who should own technologies, energy technology requirements, specific suggestions for feed in tariffs, subsidies or the like.

The strategy and market development plan is quite heavily focused on demonstration projects – funded partly by private companies and public institutions. The general assumption is that the ongoing and planned demonstration activities will provide the information and understanding of the framework conditions necessary for a RES FCHS market to develop. Currently the technology is too expensive to be competitive even in a subsidized market. This is however likely to change within the coming years as a consequence of technological development and creation of the partly publicly funded early demonstration markets paving the way for massive cost reductions due to mass production and economics of scale. The following calculations will provide us with a status quo picture of the economy of the systems as well as with an estimate of the public subsidies required in the medium term for this technology to become competitive.

3.2. Discussion of inputs and assumptions used for calculation purposes

The calculations are made on the basis of the 2 planned demonstration projects in Herning; the new Herning project now named “H2College” consisting of 16 units and H2PIA consisting of 200 units.

To supply the passive house with the heat and electricity required on an annual basis we use a 0,75 kWe LT PEM fuel cell system with the following characteristics[2].

Electricity demand kWh/year		1800
Heat demand kWh/year		5000
Fuel-cell capacity kW-el		0,75
Fuel-cell capacity kW-th		0,63
Fuel cell efficiency kWh-el/Nm3		1,44
Fuel cell efficiency kWh-th/Nm3		1,22
CHP energy efficiency		0,76
Burning value	HHV	3,5

Based upon the number of households in the project we can calculate the size of the electrolyser required for the 2 projects. The calculations can be seen in the table on the next page:

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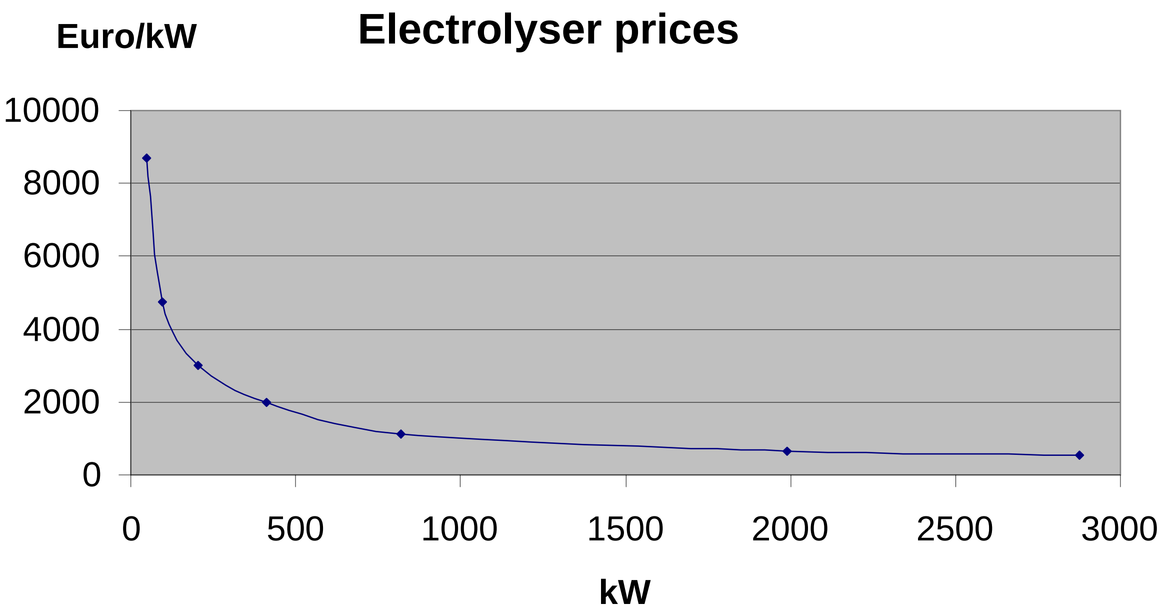
[2] For further information about this fuel cell system see WP 4.2 section 3.2

Sizing of electrolyser		
Daily electricity production max. kWh	12	12
Fuel cell efficiency kWh/Nm3	1,44	1,44
Daily hydrogen consumption max. Nm3	8	8
Number of operation hour per day	8	8
Size of electrolyser Nm3/h per house	1,04	1,04
Number of houses at the estate	200	16
Size of electrolyser Nm3/h	208	17
Electrolyser efficiency kWh/Nm3	5	5
Size of electrolyser kW	1042	83
Heat production from electrolyser per house kWh	1988	1988

The cost of the electrolysers required for these 2 projects is estimated from the price curve below:



Source: WP4.2, paragraph 4

A look at the cost curve tells us that a 83 kW plant roughly cost 5000 euro per kW which equals a total systems price of roughly 415.000 Euro.

The 1 MW system cost considerably less per KW – roughly 1000 euro/kW which equals a total systems price of 1,042 mio. euro.

The hydrogen production cost per Nm3 can be viewed in the table below. As foreseen the hydrogen price becomes considerably cheaper when we size up our demonstration projects and the electrolyser. As it can be seen in the figure above the “pricecurve” flattens between 1 and 3 MW which implies that the optimum possible hydrogen price today can be obtained by building electrolysers sized to supply clusters between 200 and 600 passive houses. Scaling up the electrolyser from 1 to 3 MW only decrease the hydrogen price from 0,28 to 0,22 euro/Nm3.

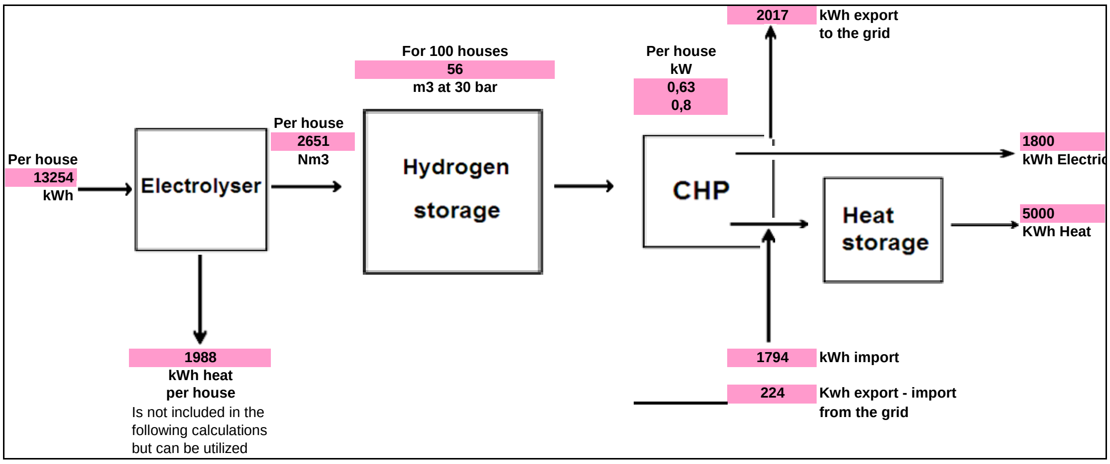
However since depreciation on the FCHS pt. accounts for the major part of the overall systems cost for the individual end consumers; getting the price down on the hardware in this part of the overall system is the most important task. Decreasing cost in other parts of the system shall off course be pursued whenever possible.

In the wind/H2 scenario it is in some regions not, due to economic reasons, possible to establish large FCHS clusters. In these cases it can prove beneficial to establish cooperation with other projects also requiring hydrogen and thereby increasing the hydrogen demand and thus the size of the electrolyser. This can be done by establishing fuelling stations for H2 vehicles in connection to the project or locating the houses near an industry requiring H2 for their production processes.

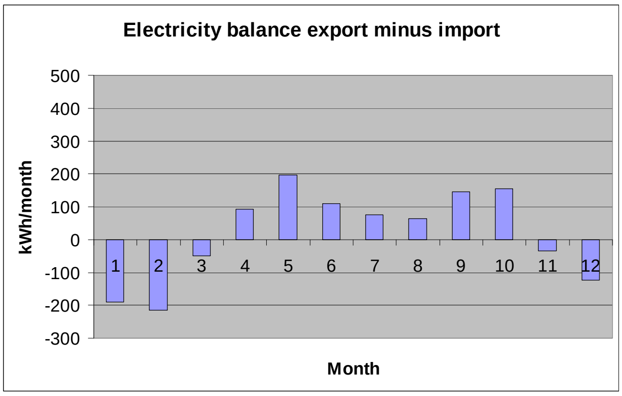
Price of hydrogen via Electrolyses:	H2College		H2Pia	Euro/Nm3
Price of electricity at average off peak time Euro/kWh	0,0307		0,0307	
Efficiency kwh/Nm3 hydrogen produced	5		5	
Price of electricity at off peak time Euro/Nm3 hydrogen produced		0,15		0,15
Size of electrolyser kW (from calculation)	83		1042	
Price of electrolyser per kW, Euro/kWh (from curve)	5000		1000	
Price of electrolyser, Euro	415.000		1.042.000	
Number of operation hours per day	8		8	
Life time of electrolyser in years	10		10	
Depreciation per kWh consumed by the electrolyser, Euro	0,171		0,034	
Depreciation per Nm3 produced by the electrolyser, Euro	0,60	0,60	0,12	0,12
Maintenance costs		0,0060		0,0060
Price of hydrogen		0,76		0,28

3.3. System setup and energy efficiency

The system setup in the 2 Danish projects under investigation is shown in the figure below, and corresponds with the wind/H2 descriptions made previously in this study.



As it can be seen in the figure the FCHS has a relatively large electricity exchange with the grid during the year. The net exchange per month can be viewed in the next figure:



Over the cause of a whole year this electricity exchange adds up to a net export of 224 kWh, which under the solar cell legislation will not be settled.

The H2College project is currently under construction and will be operational ultimo 2008. The consortium behind the FCHS part of the project include research institutions, an electrolyser manufacturer, a FCHS manufacturer, a heat storage manufacturer, the local municipality, consulting engineers as well as a local natural gas company (hydrogen grid provider). Since this is the first project of its kind in Denmark, a large number of practical issues have to be looked into such as safety approvals of individual components as well as the entire system, taxation issues, agreements with the local electricity company as well as the TSO; Energinet.dk.

It is vital that all these types of stakeholders are involved in the demonstration projects. They are necessary to involve for several reasons. In the initial phases the partners are vital to secure the funding required for the projects as well as to solve the technical problems. In a longer term perspective their involvement is necessary to secure a portfolio of competent sub suppliers and to establish the necessary framework conditions. Last but not least a number of the stakeholders are likely future owners/operators of FCHS's, and the systems therefore need to be developed to fulfil their specific requirements in order to become truly successful. One of the requirements that can be very beneficial to investigate is how these systems can operate in the market for power regulation.

The households in the H2College project are located next to a large student house, which will be heated by the surplus heat from the electrolyser. In this way the overall energy efficiency is improved by 15% which equals an economical value of 1988 kWh heat/per FCHS or 260 Euro/FCHS/year. The inputs and outputs of the entire system can be viewed in the table below.

System input:	No heat utilization	H2College	
Electricity from wind turbines	13254	13254	kWh / year
System outputs:			
Heat from electrolyser	0	1988	kWh / year
Electricity to one house	1800	1800	kWh / year
Heat to one house	5000	5000	kWh / year
Netto export of electricity	224	224	kWh / year
Sum of outputs	7024	9012	kWh / year
System energy efficiency	0,53	0,68	

In the H2pia project is has not yet been decided upon how to utilize the heat from the electrolyser, but several possibilities will be thoroughly investigated, since the overall economy of these systems is positively affected by improved energy efficiency. Different means of improving overall energy efficiency in these systems is definitely also among the important areas the demonstration projects shall and will find innovative solutions to – for economical as well as environmental reasons.

3.4. Economy of the FCHS

An estimate of the consumer economy of the 2 projects is calculated in the table below:

	H2College	H2Pia	H2Pia no tax	Break even
Net price of hydrogen used by CHP Euro/ Nm3	0,76	0,28	0,28	0,28
Grid payment per kWh	0,007	0,007		
Grid payment per Nm3	0,0245	0,0245	0	0
PSO per kWh	0,019	0,019		
PSO per Nm3	0,095	0,095	0	0
CO2 per Kwh heavy process	0,004	0,004		
CO2 per Nm3	0,02	0,02	0	0
Electgricity tax per kWh	0,001	0,001		
Electricity tax per Nm3	0,005	0,005	0	0
Sum of tax ex. VAT	0,12	0,12	0	0
VAT % 25	0,19	0,07	0,07	0,07
Hydrogen price incl. tax per Nm3, Euro	1,09	0,49	0,35	0,35
Costs of hydrogen per house per year ex. depreciation Euro	2.901	1.311	928	928
Price of CHP Euro	28.600	17.600	17.600	2.300
Lifetime of CHP year	5	5	5	5
Depreciation of CHP Euro/Nm3 hydrogen	2,16	1,33	1,33	0,17
Depreciation of CHP Euro/kWh hydrogen	0,62	0,38	0,38	0,05
Depreciation of CHP per year	5.720	3.520	3.520	460
Costs of hydrogen per house per year incl. depreciation Euro	8.621	4.831	4.448	1.388
Consumer price of electricity incl. tax, Euro/kWh	0,27	0,27	0,27	0,27
Consumer price of heat incl. tax, Euro/kWh	0,13	0,13	0,13	0,13
Value of electricity production from CHP Euro	970	970	970	970
Value of heat production from CHP Euro	417	417	417	417
Value of CHP production per year	1.387	1.387	1.387	1.387
Value of CHP production minus cost of hydrogen	-7.234	-3.444	-3.061	-1
Heatproduction from CHP kWh	3206	3206	3206	3206
Electricity production - net export kWh	3594	3594	3594	3594
Costs relatet to heat production per year Euro	2802	1570	1446	451
Costs relatet to heat production Euro/kWh	0,87	0,49	0,45	0,14
Costs related to electricity production per year Euro	5819	3261	3002	937
Costs related to electricity production Euro/kWh	1,62	0,91	0,84	0,26

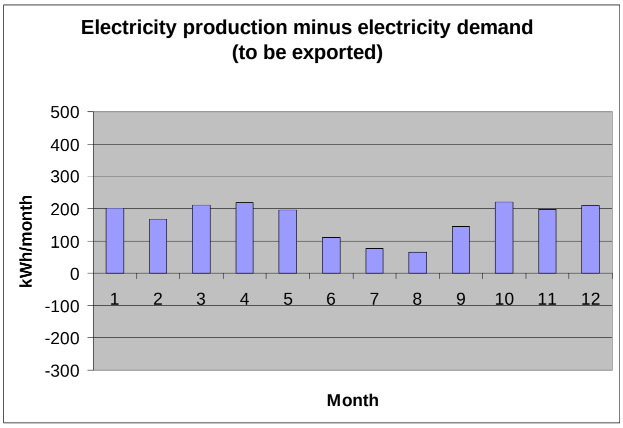
These calculations is not including costs of establishing a hydrogen distribution network from the electrolyser to the individual households, nor is the calculations including interest of the investment in electrolyser or CHP's.

As it can be seen in the first two columns of the table the prices of electricity and heat for the consumer in the 2 planned projects is not competitive to traditional technologies with the present H2, electricity/heat and FCHS prices. The extra cost per year for supplying a household with heat and electricity from a FCHS is 7234 and 3444 Euro/year respectively. It is far from competitive but it is very interesting (and promising for the technology) that the extra cost per household decreases more than 50% by expanding the project from 16 houses (2008) to 200 houses (2009).

A tax exemption (column 3) could further improve the economy of the systems to have an annual extra cost for the end consumer of app. 3000 Euro/year. It is likely that a small segment of green consumers are willing to invest in RES FCHS at this price. However if this technology is to have a major breakthrough it has to become competitive for end consumers. The price at which a FCHS is competitive is approximately 2300 Euro (without heat utilization of the electrolyser). If a subsidy programme is introduced the breakeven price will off course be higher. The need for introduction of subsidy programmes for hydrogen technologies has been acknowledged by the Danish Energy Authority, and is likely to be introduced as soon as the technology reaches a price level where such a programme is appropriate.

The subsidies required, in form of feed in tariffs and tax exemptions, are possible to reduce by letting the electrolyser operate on the market for regulating power and thus giving the system owners a payment for the grid regulating and electricity storage service they deliver to the system. This grid regulating service will no doubt become increasingly necessary (and thus valuable) as Denmark increases the dependency of RES in the Energy supply.

This is a very important area to investigate, and how the operation on the market is to be handled in practise, is being looked into in connection with the Nakskov demonstration project. How to incorporate the electrolyser and the FCHS in a “virtual” power pool is not a simple task. It is likely that it will take a while to develop the appropriate control systems, optimize the operation strategies, the sizing of the electrolyser and corresponding storage facilities of the system to operate on the market of regulating power.



4. COST CALCULATIONS AND IMPROVED FRAMEWORK CONDITIONS FOR BIOGAS BASED FUEL CELLS IN DENMARK

By Frede Hvelplund, Aalborg University and Claus Torbensen, HIRC

4.1. Introduction

When analysing costs and market framework conditions for the development of a new fuel cell technology two main areas has to be analysed:

(a) Which is the optimum version of this new fuel cell technology, under given market framework conditions.

(b) Which are the market framework conditions and how should framework conditions look like in order to further the fuel cell technology in such a way that this technology gets similar conditions as other sustainable energy systems.

The aim of this analysis then is to establish framework conditions that can further the development of the new fuel cell technology by creating a level technological playing field with other renewable technological solutions having similar abilities in solving important problems at the energy scene.

4.2. The optimum biogas fuel cell system in the Danish system

Biogas based fuel cells have to be treated very different from electricity based fuel cells in a wind energy system. This is due to two reasons: (a) Biogas is converted to hydrogen in a chemical reformation process and not, as in the case of wind based electricity, in an electrolysis process, (b) upgraded and cleaned biogas can be distributed in the already existing Danish natural gas distribution system.

It therefore will be much too wasteful both thermodynamically and economically to produce electricity at a biogas plant and convert this electricity to hydrogen through an electrolysis process. Thermodynamically wasteful as the energy contents in the biogas will only result in less than 10% electricity plus 80-85% heat and around 10% waste heat. So this system therefore can be excluded in our search for the best system.

Another system illustrated in figure 2 could be that biogas is upgraded to syngas close to or at the biogas plant, and then distributed via the natural gas network[3]. Regarding the energy-efficiency of upgrading biogas the following energy losses is to be taken into account[4].

0,5 - 2 kWh el./ m3 raw gas for CO2-eliminiation
0,4 kWh el. / Nm3 raw gas for compression
2 % Methane losses

This adds up to an energy loss in the process of between 14 and 35% dependant upon the initial CO2 content of the biogas.

In case 1 the upgraded gas is distributed to a syngas (NG)-hydrogen reformation plant, and via a hydrogen network distributed to household fuel cells. This system would have an electricity efficiency of around 25%. It is linked to the construction of a setting of for instance 100 new low energy houses, where a local

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[3] In the following systems we assume that there has been found a solution for the problem linked to the fact that the cleaned and upgraded biogas (here called bio methane) has a lower heating value than average natural gas. This encompasses no serious technical problems, but it gives problems linked to payment for bio methane and natural gas.
[4] These figures are provided by Katrin Pietzsch, IBBK, Germany

hydrogen distribution network is constructed. On a short term basis the hydrogen reformer can be located close to existing district heating systems, and in that way the heat from the reformation process could be used without having to build a new district heating network and the overall energy efficiency can be as high as 60-65% (25% el + 35-40% heat).

But as new long term sustainable system it has the obvious problem of having to build both at district heating network and a hydrogen network in addition to the already existing electricity network.

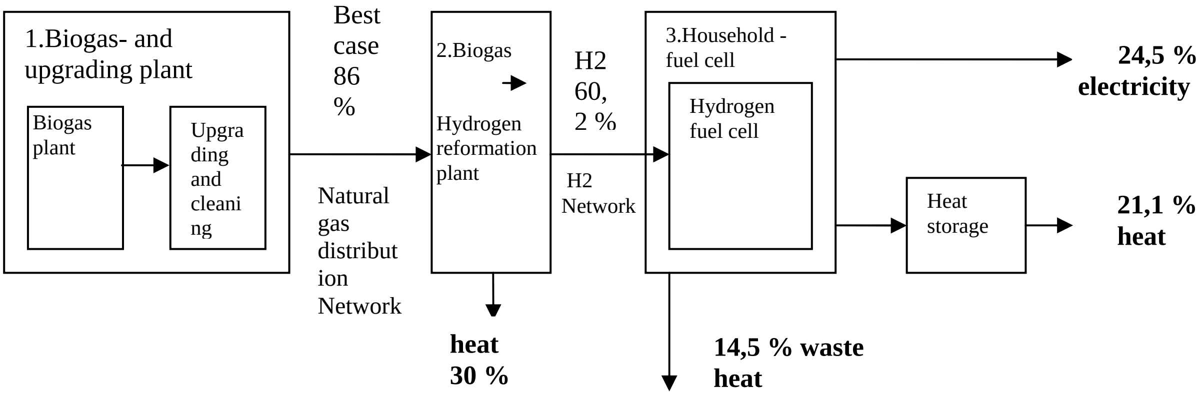

Figure 1. Biogas - fuel cell system with a central hydrogen reformation plant.

Economically it has, in an introductory phase the following implementation advantages and disadvantages:

A. Economic advantages

It can be argued that a central reformer for 100 units being able to reform 100.000 m3 bio methane annually may be cheaper than a household reformer, with a projected future cost of approximately 1300-2000 Euro for a unit that can reform 1.000 m3 bio methane annually. On the other hand the small household units can be produced in large numbers and thus benefit from economies of scale. Furthermore a central unit requires a house and a place to stay. So altogether this economic advantage may be nonexistent.

The payment for transportation of bio methane in the natural gas network is digressive, where there is a high price for the first 20.000 m3 bio methane transported, and a lower price for the next units transported.

B. Economic disadvantages

- Investment in district heating network needed.
- Economic losses linked to heat loss in the central reformation plant and district heating network.
- Investment in a local hydrogen network is needed
- Necessary to link it to new houses in a new housing area. This makes it less interesting for a large market implementation.

A third system is the one illustrated in figure 2, where biogas is upgraded and cleaned at the biogas plant and distributed to the households by means of an existing natural gas network. The biogas then is used in each household by means of a COMBI fuel cell, consisting of a reformation unit transforming natural gas to hydrogen, and a fuel cell unit transforming the hydrogen to electricity and heat. This unit is at present being developed at amongst others Danfoss, and is expected to be ready for commercial production around 2010 - 2012.

This “third system” seems to be the best biogas fuel cell system on a medium term basis as it can start the market development of household fuel cell units within the existing Danish natural gas distributions system. There are around 380.000 individual family houses within the natural gas distribution system. Here the market and fuel distribution network already exists, and it is possible to concentrate the fuel cell development on the market on “only one” really new component, namely the household COMBI fuel cell. It should be underlined that the fuel cell units in both systems, figure 1 and figure 2, are similar. This means that the COMBI fuel cell unit is a figure 1 unit plus a natural gas- hydrogen reform unit.

Consequently it is possible to benefit from the economies of scale when producing and buying these units, with regard to the fuel cell part of the unit. So if one want to buy 3.000 units, and for instance 1.000 out of these are COMBI units, there will still be a need for producing 3.000 similar fuel cell units.

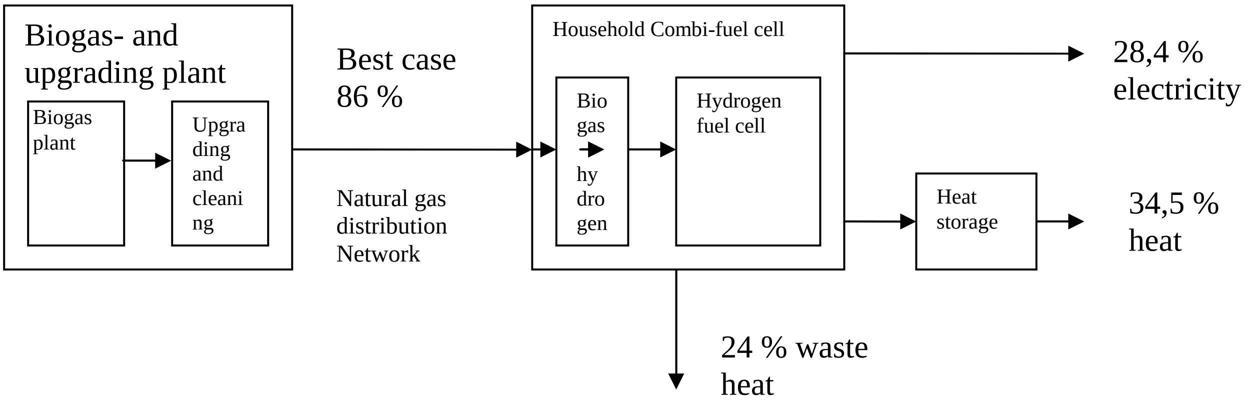

Figure 2. The biogas – COMBI fuel cell system

Explanation: The system consists of:

a. A biogas plant.
b. A plant for upgrading and cleaning biogas to the same heating value as natural gas.
c. The existing natural gas distributions system.
d. A COMBI bio methane- hydrogen reform unit + a fuel cell unit placed in the house, where the upgraded and cleaned biogas is reformed to hydrogen, which then is converted to electricity and heat in a fuel cell.

This system has the following implementation advantages and disadvantages:
(Economic advantages compared with the figure 1 system with a central reformer)

- Not necessary to build a district heating system
- Not necessary to build a hydrogen distribution system
- Not necessary to link it to new houses.
- No loss of heat in a district heating system.

Economic disadvantage

The household pays a high price per m3 bio methane transported in the natural gas distribution network, due to the low consumption. The payment is digressive.

The biogas system with a COMBI fuel cell at the household level is the one closest to economic implementation on a medium term basis. This system will be used in the following calculations.

The total energy efficiency of the system (28,4% el + 34,5% heat) equalling 62,9% is a significant improvement compared to the traditional method of utilizing biogas. The traditional use of biogas (burning in internal combustion engines) has an efficiency of approximately 40% el, and roughly 20-25% non process heat - which in theory can be utilized externally through a district heating network. However the majority of biogas plants are located far from the urban areas where district heating is used, so in most cases the relevant energy efficiency number to use as a means of comparison is 40%.

4.3. The cost of heat and electricity from biogas - decentralised - COMBI fuel cell system

I. Costs of upgraded and cleaned bio methane[5] *(biogas with this heating value can be distributed in the natural gas network)*

a. Cost of producing 1.54 m3 biogas (9.7kWh) = 0.12 -0.14 Euro
b. Costs of cleaning and upgrading 1.54 biogas to 1 m3 bio methane = 0.22 -0.29 Euro
c. Total cost of producing 1 m3 bio methane (9.7 kWh) = 0.34 -0.43 Euro
d. Distribution = 0,13 Euro
e. Total cost = 0,47 -0,56 Euro

According to Danish Gas technical center we can expect to pay 13.4 Eurocent/m3[6] for the use of the natural gas distributions system. This tariff applies for an annual consumption per consumer on less than 20.000 m3.

II. Cost of producing heat and electricity at the COMBI-fuel cell

Regarding the cost of the COMBI-fuel cell with a power capacity of 1 kWe, we have obtained the following estimations[7]. The prices in the figure are to be multiplied with 0,8 to obtain the price of a 0,5 kWe system. It should be underlined that these estimations are somewhat uncertain.

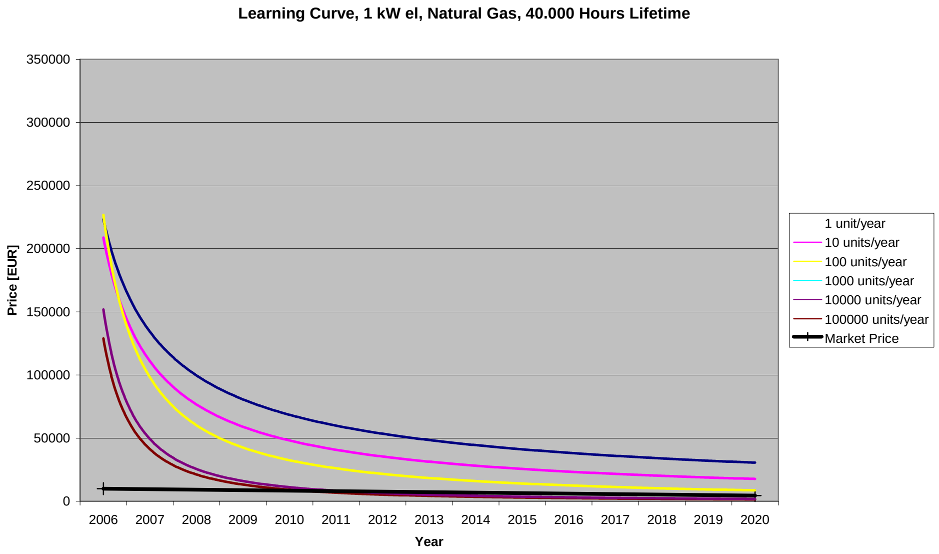

Figure 3

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[5] Based on information from Jens Bo Holm Nielsen, Head of Bio energy Department, Aalborg University.
[6] Interview with Per Christensen DGC.
[7] Based on information from Per Balslev, DANFOSS and Jesper Themsen, Dantherm.

The technical lifetime of the COMBI-fuel cell unit is designed for 40.000 hours, or between 6 and 7 years of use. Nevertheless the manufactures argues that for the first systems the depression period should be only 5 years.

Operation and maintenance costs are in the range of 67 Euro to 134 Euro per year. This is not included in the following calculations, as we are using a rather short 5 years depreciation period.

In the following we will make some explorative calculations on the system previously shown in figure 2.

4.4 Biogas- fuel cell system with decentralised household COMBI- fuel cells

The characteristics of the COMBI-fuel cell system we work with is as follows: Size around 180 cm high and, 60 broad and 60 deep.

For our calculations we use the following fuel cell data provided by Dantherm:

Fuel-cell capacity kW-el	0,5
Fuel-cell capacity kW-th	0,65
Fuel cell efficiency kWh-el/Nm3	3,63
Fuel cell efficiency kWh-th/Nm3	4,73
CHP energy efficiency	0,76
kWh/nM3 hydrogencarrier*	11

Table 1: * The figure is HHV for natural gas, which is the fuel the above mentioned figures are derived from, as well as it is the real burning value of the input to the FCHS even though parts of it is biomethane (9,7kW/nM3).

We are calculating upon the passive house scenario described in paragraph 2 covering all 3 Danish FCHS scenarios.

The system is grid connected and the fuel cells are running according to heat demand, which implies that we get a rather large and continuous electricity exchange with the grid. In the following calculations it is assumed that electricity exchange legislative wise will be treated similar to solar power in Denmark – meaning that household consumption is settled on a yearly net account basis. Annual net export is not settled under this arrangement. In the calculations we assume no tax on biogas.

4.5. Calculations

The 0,5 kWe fuel cell can cover the energy need of 4 people in a passive house with an annual consumption of upgraded biogas (NG) totalling 897 nM3/year - and will as it can be viewed in the figures below furthermore yield an annual electricity export – in this example 688 kWh/year.

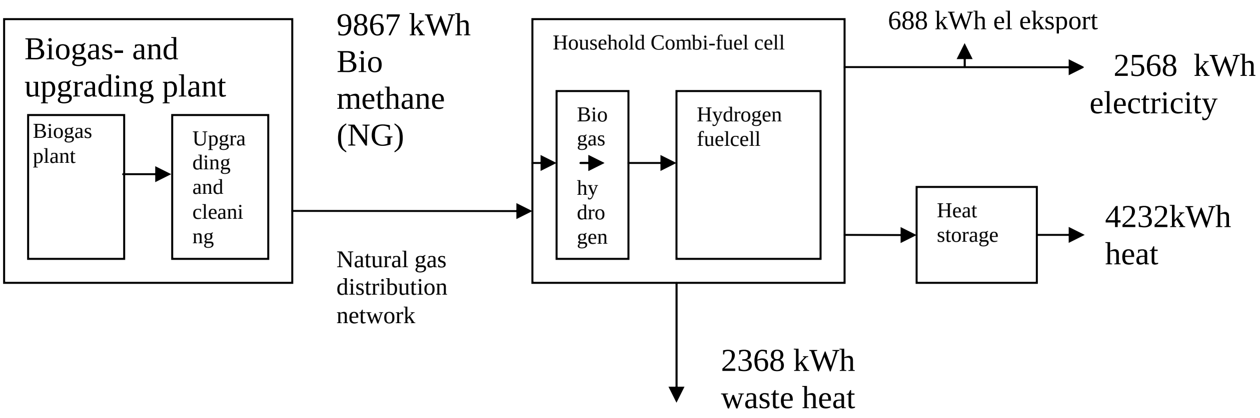


Figure 4: Systems design

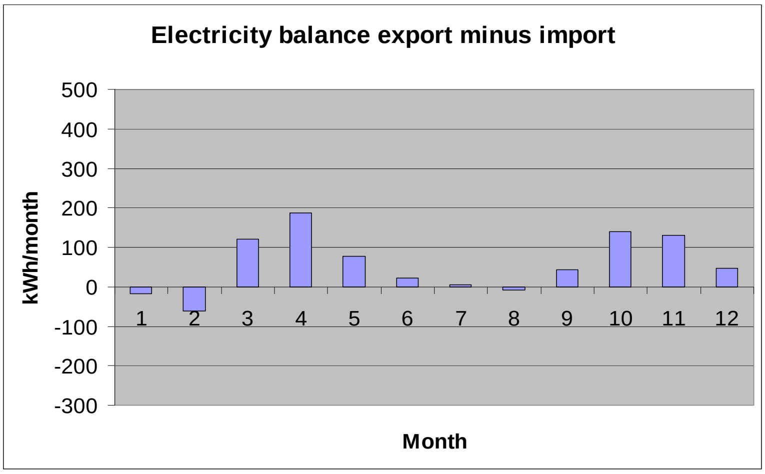


Figure 5: Annual electricity balance

For the cost analysis of this system we use the FCHS cost estimates for 50 units – which is the combined number of LT PEM based FCHS planned in the first phase of the Nakskov/Sønderborg project. Looking at the cost curve in Figure 3 the systems will cost approximately 45000 euro*0,8 =36000 euro a piece.

Even though we in theory purchase upgraded biogas – this gas is mixed with NG in the pipes and in praxis the fuel for our systems will be mostly NG - with a higher burning value than the upgraded biogas. Therefore the burning value of NG is used in the calculations. When we are to settle our account, a logic way to do it will be to purchase theoretical bio methane, as it is currently possible to purchase theoretical wind electricity in Denmark (for a small premium on the electricity bill).

Theoretical consumption of bio methane:

Consumption of NG* (burning value NG/burning value bio methane)
897 nM3*(11/9,7) = 1017 nM3.

The price used in the calculations for bio methane in NG equivalents is thus
(1017nM3/897nM3)*(0,47-0,56 euro/nM3) = 0,53 – 0,63 euro/nM3
Using these figures for calculations of the economy of the system we obtain the following results:

		Cheap A	Expensive B	Break even	10000 units 2012 D
Net price of hydrogen carrier used by CHP Euro/ Nm3		0,53	0,63	0,53	0,53
VAT %	25	0,13	0,16	0,13	0,13
Hydrogen carrier price incl. tax per Nm3, Euro		0,66	0,79	0,66	0,66
Costs of hydrogen per year ex. depreciation Euro		594	706	594	594
Price of CHP Euro		36.000	36.000	3.250	4.320
Lifetime of CHP year		5	5	5	7
Depreciation of CHP Euro/Nm3 hydrogen carrier		8,03	8,03	0,72	0,69
Depreciation of CHP Euro/kWh		0,73	0,73	0,07	0,06
Depreciation of CHP per year		7.200	7.200	650	617
Costs of hydrogen carrier per year incl. depreciation Euro		7.794	7.906	1.244	1.211
Consumer price of electricity incl. tax, Euro/kWh		0,27	0,27	0,27	0,27
Consumer price of heat incl. tax, Euro/kWh		0,13	0,13	0,13	0,13
Value of electricity production from CHP Euro		693	693	693	693
Value of heat production from CHP Euro		550	550	550	550
Value of CHP production per year		1.243	1.243	1.243	1.243
Value of CHP production minus cost of hydrogen carrier		-6.551	-6.663	-1	32
Heatproduction from CHP kWh		4232	4232	4232	4232
Electricity production - net export kWh		2568	2568	2568	2568
Costs related to heat production per year Euro		2533	2570	404	394
Costs related to heat production Euro/kWh		0,60	0,61	0,10	0,09
Costs related to electricity production per year Euro		5261	5337	840	818
Costs related to electricity production Euro/kWh		2,05	2,08	0,33	0,32

With the current prices of the system the COMBI-fuel cell units this system is far from attractive for the end consumers. Heat and electricity for the household will in both bio methane cost scenarios; A and B cost in excess of 6500 euro more per year than what the consumers currently pay. This is far more, than what even the most environmental consumer is willing to pay. Therefore the first demonstration projects of this technology have to rely upon significant public funding. The Danish Sønderborg/Nakskov project is partly funded by the national energy research programme EUDP and H2College project is partly funded by funded by the municipality and the regional government.

The break even price for this technology prices (fixed fuel and energy prices) is 3250 euro which is less than 10% of the systems price today. However this price target is within reach and the price estimates from Dantherm in 2012 is 5400*0,8 = 4320 euro (10.000 units/year). Calculating with these figures and assuming a longer lifetime of the systems in 2012 and thereby a longer depreciation period (conservatively 7 years) will make these systems profitable for the end users.

4.6. Establishment of a level renewable energy playing field supporting the development of renewable energy based fuel cells

It is difficult in the present situation to decide which type of biogas based fuel cell systems one should select. In this paper we recommend a COMBI fuel cell system as the best one, but we may be wrong. It also is difficult to decide upon whether it is a good idea to use the biogas in fuel cell based household cogeneration systems, or a system consisting of using biogas in larger cogeneration units plus using solar and wind energy based heating systems in individual houses. Consequently one cannot just establish framework conditions supporting one technology, but rather establish framework conditions that support a levelled playing field for the competition between different renewable energy solutions. Nevertheless it is, in the initial phases of technological development necessary with a sort of direct support for specific technologies with a possibility of having a promising future in the energy system.

In this case we suggest a 2 phase support system, where only phase 1 is to be directly tailored for the biogas fuel cell system.

Phase 1: 2008-2010:

The establishment of a prototype stands of around 50 units. This should include support for prototypes within the following technologies:

- A prototype system for cleaning and upgrading biogas.
- A system for using and measuring this bio methane in the natural gas system.
- 200 COMBI- fuel cell units bought together with fuel cell units for the wind energy- hydrogen system.

The aim of this phase is to learn how the technology chain functions.

Phase 2: 2009-2012:

The phase 2 rules should be introduced as soon as possible. (It does not matter that there are clear rules before a technology is cheap enough to use the rules.)

a) Introducing a legislation that gives clear rules for the payment for gas transportation in the natural gas network.
b) Making sure that households have a contract with a bio methane producer and can buy bio methane without paying energy tax.
c) A COMBI fuel cell can get a 30% investment subsidy for plants build in the period 2009-2012.

These conditions (a, b, c) should be applicable to all not yet technological ripe technologies using renewable energy.

In order to avoid socio-economic losses, a level playing field should be established for renewable energy technologies. This means that similar conditions should be established for wind power for heat and electricity production. As wind power is a relatively ripe technology, it should not have the 30% subsidy. Legislation should be introduced making it possible for single households to buy wind power for heat and electricity purposes when using the energy efficient heat pump technology, with clear rules for payment for transportation in the electricity grid system, and no tax on electricity where the customer has a contract with the wind energy producer.

5. COST FOR METHANOL BASED FUEL CELLS IN DENMARK

By Martin Møller, DONG

5.1. Reduced cost due to pooling the orders

As discussed in WP 4.2 the supply cost of methanol will most likely not be influenced by improved framework, as it is already traded in very large volumes on the world market. In the (m)ethanol case the only cost that can be reduced will be the cost for the methanol reformers and the FC units in the household.

5.1.1. FC-units

The FC unit used in this case is identical with the FC units used in all the other regions and cases, the effect of reduced cost will not be discussed here. For the calculations the figures provided by Dantherm has been used. Dantherm predicts a price of 16.000 Euro for a 0,5 Kwe unit in 2009, if 200 units are ordered. The lifetime is assumed to be only 5 years before a major overhaul is needed.

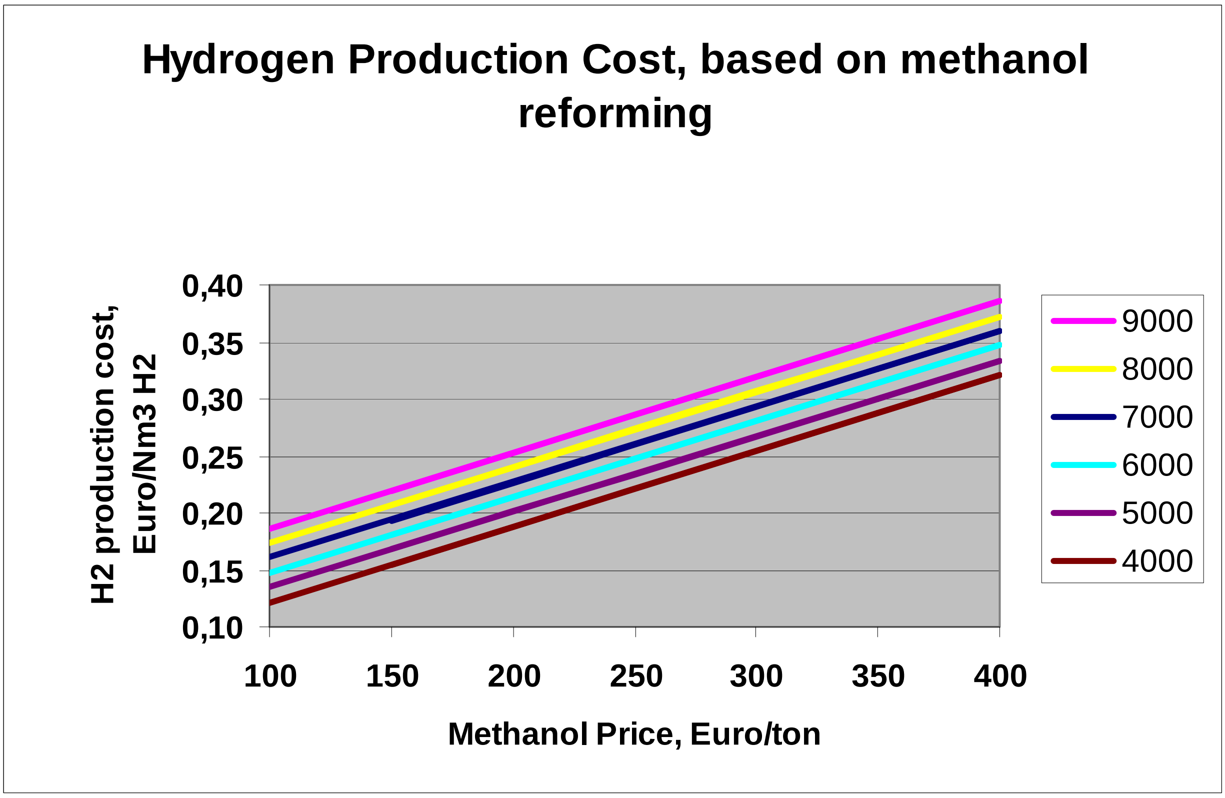
5.1.2. Methanol reformer

From WP3 the largest cluster in the region identified is the H2PIA-project, which consists of around 200 units. Such a region can utilize a common methanol reformer in the size of 150 Nm^3/hr, which is in the range of commercial available methanol reformers.

Each cluster will need one methanol reformer, in order to supply hydrogen to around 200 households. In the most optimistic case 10 methanol reformers can be procured together, but as they are already a mature technology, it will be a limited discount that can be obtained. The calculations below are based on a commercial offer for a methanol reformer shown on appendix 1. The offer includes most of the hardware needed, except from foundations and eventually buildings needed. It has only been possible to obtain an offer from the Danish company Haldor Topsoe.

5.2. Calculated hydrogen production cost

Based on the technology chosen, the hydrogen production cost has been calculated. The cost is expressed as the cost of hydrogen delivered at the entrance to the hydrogen grid needed in the cluster of 200 RES-FC units of 0,5 KWe. The cost does not include the cost of the necessary hydrogen grid. The offer obtained for the methanol reformer hardware is based on a reformer suitable for 400 houses, but the cost per 1 Nm3 H2 is not expected to vary much, if it has to be based on 200 houses. It has only been possible to obtain the offer for a size corresponding to 400 houses. The specific reformer cost for the 400 houses is 2.000.000 Euro / 300 Nm3 H2 /hr = 6.667 Euro Nm3 H2 / hr of installed capacity. For detail please look at appendix 2.



The above graph shows the calculated hydrogen production cost, as a function of both the methanol price, and the reformer hardware price in Euro Nm^3 H_2 / hr of installed capacity. The reformer hardware price is varied from 9000 to 4000 Euro per Nm^3 H_2 / hr of installed capacity. A realistic hydrogen productions cost based on fossil methanol price of 145 USD/ Ton (110 Euro/ ton) is in the range of 0,12 – 0,18 Euro/Nm^3 H_2. From the graph it can also be concluded that the methanol price, has a larger effect on the hydrogen price, than the reformer hardware price.

When the methanol feedstock price is changed 50%, the hydrogen productions cost is changed 34%, but when the reformer hardware is changed 50%, the hydrogen production cost is only changed 8 %.

Effect of methanolprice Vs effect of reformer cost

Reformer	7000	Euro/Nm3		
Methanol Price	300	Euro/Ton	0,29	Euro/Nm3 H2
Methanol Price	150	Euro/Ton	0,19	Euro/Nm3 H2
Price reduction	50%		34%	

Methanol Price	250	Euro/Ton		
Reformer	8000	Euro/Nm3	0,24	Euro/Nm3 H2
Reformer	4000	Euro/Nm3	0,22	Euro/Nm3 H2
Price reduction	50%		8%	

5.3. Conclusion on effect of pooling the orders

As the methanol is already traded in the world market, in much larger volumes, than that can be used in this project, there will be no advantage in methanol procurement. The above calculation of the hydrogen production cost, conclude only a minor effect of pooling the orders for the reformer hardware. Therefore as previous stated focus should be laid upon pooling the orders for the micro CHP.

5.4 Specific end-user cost in a given project

Based on a region of 200 dwellings in Denmark, the economic effect for the end-user has been calculated. In this specific Danish case the following assumptions has been applied.

- 100 M2 passive house
- Yearly heat demand of 3500 KWh
- Yearly electricity demand 1800 KWh
- The electricity export on a yearly average out of the house is almost 0.
- The micro CHP is operated according to the heating demand
- Heat is valued at 0,13 Eur / KWh including tax
- Electricity is valued at 0,27 Eur / KWh including tax
- The fossil methanol feedstock is released from all energy taxes.

Six different cases has been calculated, the price for methanol, reformer hardware and micro CHP has been varied. For details in the calculations please refer to appendix 2.

Based on Appendix 2 and the above assumptions the additional cost for the end user has been calculated in 6 cases. If the additional cost for the end-user is negative, it means that the system cannot compete with the existing technologies, in terms of cost.

Summery of calculations	A	B	C	D	E	F
Reformer cost, Euro/NM3 H2	6666	6666	6666	6666	8000	4000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	110	110	310	310	200	110
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0.08	0.08	0.21	0.21	0.14	0.08
Reformer hardware cost, Euro/Nm3 H2 produced	0.084	0.084	0.084	0.084	0.101	0.050
Net price hydrogen used by CHP (excl h2 grid contribution) Euro/Nm3 H2	0.16	0.16	0.29	0.29	0.24	0.13
Price of CHP Euro	16,000	16,000	16,000	16,000	16,000	16,000
Lifetime of CHP year	10	5	10	5	10	10
Consumer price of electricity incl. tax, Euro/kWh	0.27	0.27	0.27	0.27	0.27	0.27
Consumer price of heat incl. tax, Euro/kWh	0.13	0.13	0.13	0.13	0.13	0.13
Value of electricity production from CHP Euro	988	988	988	988	988	988
Value of heat production from CHP Euro	408	408	408	408	408	408
Value of CHP production per year	1,396	1,396	1,396	1,396	1,396	1,396
Value of CHP production minus cost of hydrogen, Euro per year	-1,241	-2,841	-2,098	-3,698	-1,736	-1,024

As can be seen from the above, all the cases, gives a negative result for the end-user. Even Case F which is very optimistic with respect to the cost of methanol feedstock. Also the price for the reformer hardware has been assumed lower than realistic. Furthermore the case uses cheap fossil methanol, which has been released from all energy taxes, even though it is of fossil origin. The most realistic case is case C and D, which uses a price of renewable methanol, and hence it might be expected that it will possible to be released from energy taxes. The difference between case C and D is the lifetime of the micro CHP, which realistic is somewhere between 5 and 10 years. These cases indicate an additional end user cost in the range of 2000 –3500 euro per year.

The most important is to reduce the cost of the FC unit, if it’s assumed that 1000 units are ordered at a price of 10,500 the result will be as below:

Summery of calculations	A	B	C	D	E	F
Reformer cost, Euro/NM3 H2	6666	6666	6666	6666	8000	4000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	110	110	310	310	200	110
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0.08	0.08	0.21	0.21	0.14	0.08
Reformer hardware cost, Euro/Nm3 H2 produced	0.086	0.086	0.086	0.086	0.104	0.052
Net price hydrogen used by CHP (excl h2 grid contribution) Euro/Nm3 H2	0.16	0.16	0.30	0.30	0.24	0.13
Price of CHP Euro	10,500	10,500	10,500	10,500	10,500	5,000
Lifetime of CHP year	10	5	10	5	10	10
Consumer price of electricity incl. tax, Euro/kWh	0.27	0.27	0.27	0.27	0.27	0.27
Consumer price of heat incl. tax, Euro/kWh	0.13	0.13	0.13	0.13	0.13	0.13
Value of electricity production from CHP Euro	988	988	988	988	988	988
Value of heat production from CHP Euro	408	408	408	408	408	408
Value of CHP production per year	1,396	1,396	1,396	1,396	1,396	1,396
Value of CHP production minus cost of hydrogen, Euro per year	-691	-1,741	-1,548	-2,598	-1,186	76

As can be seen the cost are still negative from the end user point of view, even when the FC unit are reduced to 10,500 Euro. In general the end user cost is lowered in the order of 1000 Euro per year. In order to obtain a positive result for the end user, the cost of the FC unit has to be lowered to only 5000 Euro, and furthermore it’s needed to use the optimistic assumption from case F.

5.5. Conclusion on end-user cost

If cheap hydrogen through fossil methanol reformers is used in a cluster of say around 200 households in DK, it can only be feasible when the following requirements are satisfied:

1. It has to be placed in regions where the district heating is more expensive than 0.13 EUR / KWh. This means that it has to be in regions far from the existing and rather developed district heating network in Denmark.
2. The methanol feedstock has to be released from all energy taxes, even though is based on fossil origin, and the surplus electricity sold has to have 1 priority from a grid regulating perspective, and valued at the same price as when the end user buy electricity.
3. The produced hydrogen has to cost less than 0,13 Euro per Nm^3, which means that the methanol should be procured for less than 110 Euro / MT. Presently the price is around 300 Eur/ Mt.
4. The micro CHP can be procured for 5000 Euro or less and have a lifetime of more than 10 years.
5. The necessary hydrogen grid from the reformer to the end user and buildings necessary in connections with the methanol reformer has to be free of cost, as these additional investments are not taken into consideration when the hydrogen cost is calculated.

It is hence not realistic that the system will be feasible in the near future, even when the reduced cost for pooling the orders have been taken into consideration.

6. COST CALCULATIONS FOR METHANOL/H2 BASED FUEL CELLS IN ICELAND

By Thorsteinn Sigfusson, University of Iceland

6.1. Introduction

As it has previously been stated: Then given the exceptional situation in Iceland with the electric grid reaching almost all domestic dwellings supplying them with cheap electricity of renewable origin combined with the geothermal central heating system supplying the majority of the population, it seems clear that the use of stationary fuel cells for combined heat and power has to rely on a rather special target group.

In fact a considerable number of dwellings out in the countryside are located outside the reach of the geothermal distribution systems. There is an increasing market of summer residences many of which are built for permanent use and of considerable quality. In cases where these dwellings are not grid connected there is a market for oil heating, for propane gas heating as well as diesel and gasoline generators, small wind turbines and the like. The number of such dwellings is in the range of 10-12 thousand.

The potential market for FCHS is in these non grid connected areas and in these areas only, and as it was stated in WP4.2 then it is vital that the system use de-central methanol cracking.

However, the geographic area we have chosen for the first demonstration project (10-20 houses) is located in a not so remote and grid connected area. This has been chosen because the demonstration value is much higher in a relatively central location, combined with the fact that the systems will be much easier to service.

It is very important to notice that the system setup required by the potential future market is somewhat different from what we aim to demonstrate in the first demonstration projects. For the real market we need to develop a stand alone system that can supply the household with electricity and heat without electricity exchange with the grid. The first demonstration systems will however provide us with the knowledge, data and experience required in order to develop an energy efficient non grid connected system, which we plan to test and demonstrate in a later project.

Initial ideas for such a system could be to use a slightly bigger fuel cell or maybe just supplement the system with electric heating (internally produced) and a bigger hot water tank which combined could make it possible to avoid the necessity of import and export of electricity. No FCHS suppliers has yet developed such a control system but we have no doubts that such a system will be developed if we push for it, that there is a future market for this in Iceland (and in other remote locations worldwide), and therefore we are very interested in demonstrating and gaining experiences with operating methanol fuelled FCHS.

The cost of transporting methanol to the individual households from the production plant or storage facility will be comparable to the cost of distributing oil, which is heating alternative that will be used as a means of comparison in our following evaluation on the economy of implementing decentralized methanol FCHS.

6.2. Energy balance in the grid connected demonstration project

Even though the operation strategy and systems design is likely to become somewhat different for our “ultimate goal” - the stand alone system, then it is off course vital that the grid connected demonstration systems is being operated according to the energy needs of the household. This will be elaborated upon in the following:

As a consequence of the plan to demonstrate the FCHS systems in recreational dwellings it is not realistic to build passive houses as it is intended in most of the other planned European demonstration projects. Nor is it realistic that the owners will equip the houses with the newest and most energy efficient technology – but it is furthermore not likely that the houses will be equipped with as many electrical appliances as houses build for permanent use. The dwellings are not likely to be used the whole year – but if the dwellings an even number of days/weeks per month throughout the year the spreadsheet provided by HIRC can be used for our calculations without the need for adaptations. .

The consumption that the systems are to be able to supply is shown in the table below – and is a best guess of the average consumption in the planned demonstration project.

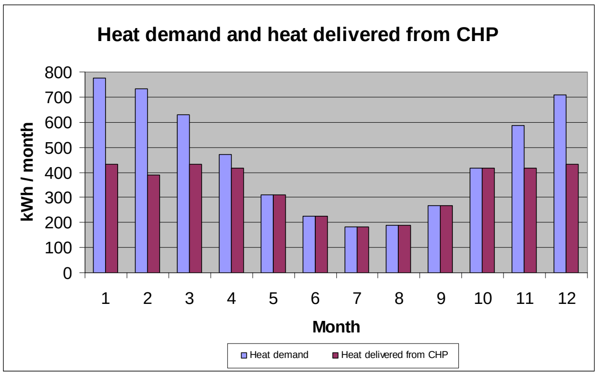
Size of one house:	100 m2	kWh/m2 year	kWh/year	kWh/day
Room heating and ventilation kWh/m2 year		25	2500	6,8
Domestic hot water kWh/m2 year (4 persons, 30 litre, delta t: 40 degree)		30	3000	8,2
Total Heat consumption kWh/year		55	5500	15,1
Electricity consumption kWh/m2		25	2500	6,8
Total		80	8000	21,9

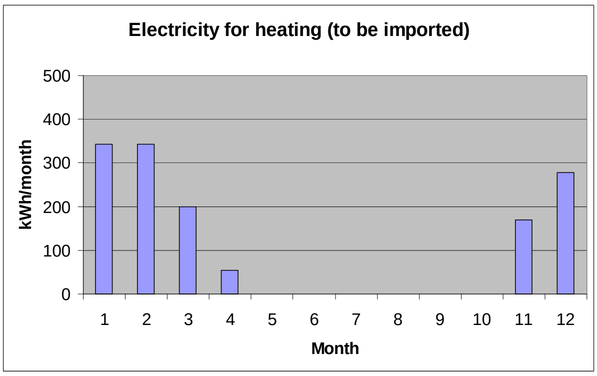
The dwellings are not likely to be used the whole year round– but if the dwellings are used an even number of days/weeks per month throughout the year, the following calculations will provide a accurate picture on whether or not the system is able to full fill the needs of the household (not in accurate numbers – but the relationship between the required electricity import and export remains unaffected).

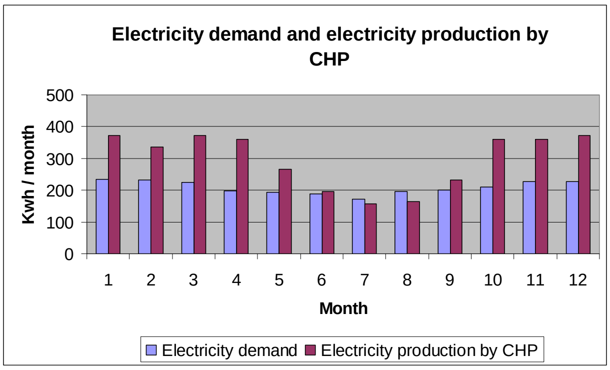
If we implement a de-central methanol FCHS with the characteristics shown in the table below a required “12 months use” net import of 342 is needed to supply the household.

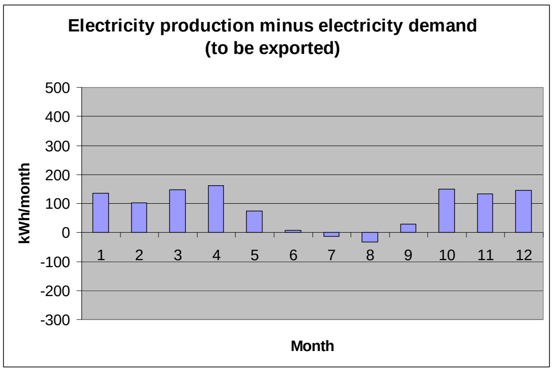
Fuel-cell capacity kW-el	0,5
Fuel-cell capacity kW-th	0,58
Fuel cell efficiency kWh-el/Nm3	1,69
Fuel cell efficiency kWh-th/Nm3	1,94
CHP energy efficiency	0,76
kWh/L hydrogencarrier	4,78

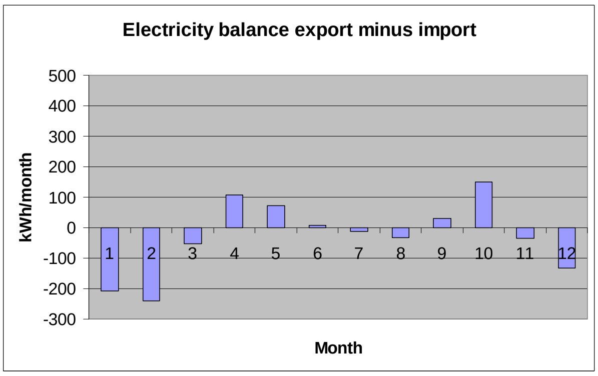
The seasonal required import/export can be viewed in the figures below:






Electricity demand and electricity production by CHP


Electricity production minus electricity demand (to be exported)


Electricity balance export minus import

6.3. Inputs for the cost calculations

The cost price we have chosen to use for our economic calculations on the operation of the FCHS's is the expected medium term methanol world market price: 110 euro/metric ton. This estimate corresponds very well with the price at which CRI International expects to be able to produce renewable Methanol for in Island in the medium term (This was elaborated upon in WP4.2).

As means of comparison for the end user economy we have used the prices for self produced electricity and heat. These prices are much higher than in the grid and geothermal heating areas but in the areas FCHS are likely to gain market shares in the future it is the only available option.

The price of self produced heat from an oil boiler in Iceland is used as a reference. This has a cost of 0,148 euro per kWh.

This value has been calculated from following input:

- Energy content in 1 litre of oil: 10 kWh
- Efficiency of oil boiler: 90%
- Price of oil boiler in Iceland incl. VAT: 5200 euro.
- Depreciation period 25 years: 208 euro/year.
- Price of 1 litre oil ex. delivery costs (Shell Iceland June 2008): 1 euro
- The system is to deliver 5500 kWh heat per year.

From these input we can calculate the heat price to:
1/9 = 0,11 euro/kWh + 208 euro/year / 5500 kWh=0,11+0,038= 0,148 euro/kWh
The price of self produced electricity by means of a (cheap) gasoline generator is as much as 0,93 euro/kWh – more than 10 times as expensive as grid electricity.

WEBSHOP

Product specifications can be viewed at http://www.powergenerator.dk/1500.html

The above generator uses 0,57 litre gasoline for the production of 1 kW electricity and with a current gasoline price of 1,63 euro/l this adds up to an electricity price of 0,93 euro/kWh.

From Dantherm's 4.2 contribution we can se that a 0,5 kWe FCHS with a de-central methanol cracker in 2009 will cost approximately 33200 if 20 systems are produced and 24900 if an annual production volume of 200 systems are reached.

Calculating on the economy of the implementation of these systems in Iceland we get the following results:

		20 houses 2009	200 houses 2009	Breakeven	3 months use/year
Net price of hydrogencarrier used by CHP Euro/ Nm3/L		0,09	0,09	0,09	0,09
Grid payment per kWh		0	0	0	0
Grid payment per Nm3/L		0			
PSO per kWh		0	0		
PSO per Nm3/L		0	0	0	0
CO2 per Kwh heavy process		0	0		
CO2 per Nm3/L		0	0	0	0
Electgricity tax per kWh		0	0		
Electricity tax per Nm3/L		0	0	0	0
Sum of tax ex. VAT		0	0	0	0
VAT %	7	0,01	0,01	0,01	0,01
Hydrogencarrier price incl. tax per Nm3, Euro		0,10	0,10	0,10	0,10
Costs of hydrogen per house per year ex. depreciation Euro		202	202	202	51
Price of CHP Euro		33.200	24.900	18.500	18.500
Lifetime of CHP year		5	5	5	20
Depreciation of CHP Euro/Nm3/L hydrogencarrier		3,17	2,37	1,76	0,44
Depreciation of CHP Euro/kWh		0,66	0,50	0,37	0,09
Depreciation of CHP per year		6.640	4.980	3.700	925
Costs of hydrogencarrier per house per year incl. depreciation Euro		6.842	5.182	3.902	976
Consumer price of electricity incl. tax, Euro/kWh		0,93	0,93	0,93	0,93
Consumer price of heat incl. tax, Euro/kWh		0,15	0,15	0,15	0,15
Value of electricity production from CHP Euro		3297	3297	3297	824
Value of heat production from CHP Euro		609	609	617	152
Value of CHP production per year		3.906	3.906	3.914	976
Value of CHP production minus cost of hydrogencarrier		-2.936	-1.276	12	1

In the first two columns of the table we can see that the end user economy improves from a minus of approximately 2900 euro/year to minus 1276 only from the price decrease from scaling up the project from 20 to 200 units - improving the end user economy more than 1600 euro. As it can be seen the last column the breakeven price for the systems are as high as 18500 euro. This is considerably higher than in the other European countries, and it is off course due to the very high electricity and heat prices for self produced heat and electricity.

It is very important to note that the calculations in the first 3 columns are based on a scenario where the houses are used 365 days a year. This is not a very realistic scenario but since the expected lifetime (depreciation period) of the FCHS is derived from the hours the system is used, then a FCHS in a recreational house will have a considerably longer lifetime in years. Hence the end user economy and break-even price (over the full depreciation period) will be the same. As it can be seen in the last column at systems price of 18500 euro a FCHS will have a payback period of 20 years (interest on the investment not included) if the house is used 3 months a year – 2 months of use will yield a 30 years of payback time and so on.

No statistics on the use of these types of dwellings exist, but a best guess is that most of the houses are used approximately 2 months a year, which equals a 30 year payback period.

Most private house owners are not willing to accept such a long payback period for their investments. We have found no data on the average payback period required for private consumers, but it is not unreasonable to assume that it is close to the payback period Danish consumers generally require for investing in new energy technologies. According to Carsten Sohl from Energitjenesten in Vestjylland, Denmark then his experience, from his work with getting private consumers to invest in solar panels, is that they require a payback period between 5 and 7 years in order to invest in new technologies.

If we apply these figures to the our calculations, then the best case (7 years) is that a “realistic investment” price for recreational house owners (using their house 3 months a year) is the calculated break even price divided by a factor 3 - equalling roughly 6200 euro. This price level is within reach, and a look at the cost curves tell us that the producers expect to be able to deliver a system at this price in 2011-2012 if more than 10000 units a year are produced.

It is also a possibility to use “short lifetime” systems for FCHS’s in this rather special market segment in Iceland. Doing so it is likely to reach a price of 6200 euro, at a lower production volume for the fuel cells – but we are still dependant upon price decreases from the volume production of the plug on methanol crackers from the long lifetime systems or other applications (e.g. power backup systems fuelled with methanol).

Summing up then there is definitely a potential future market for methanol fuelled FCHS in Iceland. There are however several things that has to happen before this market will emerge. First of all control systems for a non grid connected FCHS has to be developed and tested, and the prices have to decrease to an estimated 6200 euro per system. We believe that both factors will be fulfilled within the next 3-5 years and therefore we are very eager to get demonstration projects up and running.

7. COST CALCULATIONS FOR BIOGAS BASED FUEL CELLS IN GERMANY

By Katrin Pietzsch IBBK

7.1. Introduction to the biogas to hydrogen scenario

Biogas to hydrogen is one scenario analysed for Germany within this project. Although it is theoretically applicable in all areas where a natural gas grid exists and where biogas plants are operating nearby this scenario is only studied for the Stuttgart region which is located in the federal state of Baden-Wuerttemberg in south-western Germany. The results could, however, be transferred to other regions in the country.

Background for this scenario is the fact that Stadtwerke Esslingen (SWE) – a gas utility company close to Stuttgart – owns and operates a gas grid. SWE is generally open minded towards injecting biogas into their gas grid and towards applying new technologies such as micro-CHP, if they are economically viable. Additionally SWE supports contracting models where they operate and maintain a micro-CHP selling the electricity produced to the grid and selling the heat to the respective household.

With respect to building activities in the Stuttgart region it is known that future house builders regularly tend to form a type of cooperative in order to achieve better prices by jointly purchasing building materials. The size of such a cooperative varies between five and 25 persons with the latter number being an extreme exemption. A mean value would be ten future house builders. During the planning process those cooperatives are also looking into advantages and disadvantages of various heating systems and they are trying to find the most promising and sustainable system. Although no concrete building site has been developed yet to introduce a number of household fuel cell systems it is reasonable to study the biogas to hydrogen scenario for a building cooperative for ten households located in the Stuttgart region and using the SWE gas grid for transporting biomethane.

Under the current German framework conditions related to advancing the hydrogen economy and the application of fuel cell systems all projects should be coordinated with the National Innovation Programme “Hydrogen and Fuel Cells” (NIP) which was introduced in 2006 and has been worked over in 2007. In total the NIP provides funds of 500 Mio. Euro for R&D projects and demonstration projects. All funds are intended to facilitate market-oriented projects. Important criteria for demonstration projects are the aims to increase the system’s reliability and repeatability, to study the pattern of use, to test and to improve installation and maintenance skills of professionals as well as to identify barriers for commercialising FCHS. Of the total funds available altogether 141 Mio. Euro are allocated for demonstration projects with stationary household fuel cell systems.

Since February 2008 “NOW”, the National Organisation Hydrogen and Fuel Cells, is operating. NOW is coordinating Germany’s National Innovation Programme. Among other tasks, NOW administers the funds, is responsible for the fuel cell market development in Germany and is also the contact for demonstration projects. Approaches to develop fuel cell markets in Germany should be integrated into the national programme in order to benefit from available funds and joint forces. This way a project applying 300 FCHS can be realised.

All following calculations are based on a 100 m² passive house inhabited by a four person household.

7.2. System set-up – central vs. de-central

Within this projects' approach of using upgraded biogas (biomethane) as fuel for FCHS in a passive house two basic system set-ups are thinkable (see description of the Danish biogas scenario):

1) Biomethane is distributed via the already existing natural gas grid to a central reformer station where hydrogen is produced centrally for a housing area (e.g. 100 households). The resulting hydrogen is then delivered via a hydrogen grid to the household where it is converted into heat and power by a fuel cell. In order not to waste the heat from the reforming process a district heating system is also necessary to deliver the heat to the households.
2) Biomethane is distributed directly to the households via the natural gas grid where it is converted and used in a combined reformer-fuel cell system (COMBI system).

For both systems the basic layouts, their performance as well as their advantages and disadvantages have been described by Aalborg University for the Danish context. The results, however, also apply for the German context – especially the conclusion that the COMBI system is the more reasonable solution for operating FCHS with biomethane.

Semi-central systems might reach higher efficiencies and thus reduce losses in the reformer unit and the fuel cell. A set-up as described in option one has, however, several draw-backs. The most important disadvantages of this central scenario with a central reformer and the hydrogen grid to supply the household fuel cell systems are:

- the waste heat that is being produced by the reformer unit and
- the extra supply grid(s) that need(s) to be installed. One extra grid is required to deliver the produced hydrogen to the households.

Although several industrial hydrogen grids are currently being operated in Germany, approval authorities are not yet familiar with hydrogen grids operated in the context of housing areas. So far neither specific legislations nor regulations exist with respect to hydrogen grids in a non-industrial context. Latest experiences in Germany [HIN08] with approval procedures concerning one non-industrial hydrogen pipeline have shown that only after extensive discussions with the approval authorities it was possible to:

a) identify the appropriate authority and
b) identify the most suitable approval strategy.

A very important question that needs to be answered in this context is the question concerning the type of safety standard to be applied in housing areas. Respective regulations as well as informative campaigns and trainings for approval authorities will be developed, if the demand for hydrogen grids in non-industrial areas increases.

A second additional grid, i.e. a district heating system, is required to transport the heat to the households, if the waste heat is to be used. Costs for the pure heating grid without laying and installing the grid vary between 21 EUR and 105 EUR (incl. VAT) per meter. Furthermore every household produces heat itself when converting hydrogen in a fuel cell. Thus each household is twofold supplied with heat.

The most reasonable approach for the central scenario might be to operate a central fuel cell and to distribute its waste heat to the households via a district heating grid. Benefits arising from this configuration are reduced investment costs due to the not required hydrogen grid and higher electrical efficiencies of the central fuel cell compared to individual fuel cells.

With respect to creating markets for small scale household fuel cell systems the decentral approach is better suited. This is all the more true in that natural gas grids already exist in various parts of Germany and other partner countries. Also individual fuel cell systems connected to the natural gas grid can be installed in one household at a time, which makes their application and use independent from clustered projects. The decentral approach is therefore chosen for further calculations.

7.3. Regional background information

7.3.1. Climate

The climate of the Stuttgart region is generally mild. The average annual temperature is approximately 10°C, varying between the extrem values of 36,8 °C in summer and -21,2 °C in winter. In Stuttgart averagely 35 days per year are counted during which temperatures rise above 25 °C and 76 during which the temperature sinks below 0 °C. The average annual rainfall amounts to 668 mm.

7.3.2. Electricity

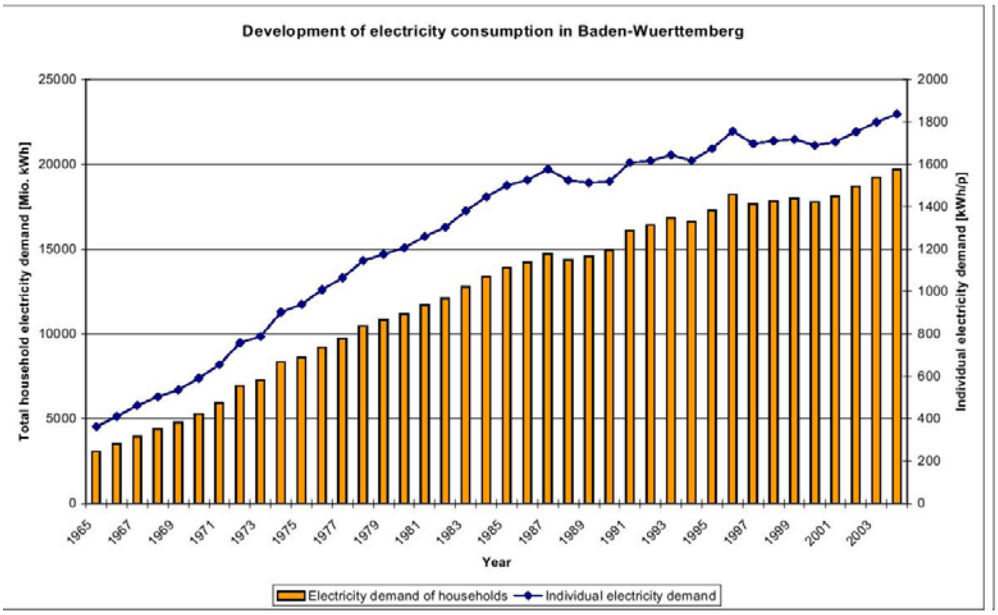


Figure 1: Development of electricity demand in Baden-Wuerttemberg (source: STA07)

With respect to the application of household fuel cell systems with an electrical power of 0,5 - 1 kW the energy consumption (electricity and heat) of the households in the regional market are of interest. In Baden-Wuerttemberg, as well as in Germany in general, a continuous rise has been observed during the last ten years [UBA2006; STA07a]. According to STA07a the total electricity demand of all private households in Baden-Wuerttemberg increased from 2.859 Mio. kWh in 1965 to 19.687 Mio. kWh in 2004. Related to the population of Baden-Wuerttemberg this means that the electricity demand of each inhabitant has been rising.The main reasons for this increase are a constantly growing population due to migration to Baden-Wuerttemberg, the growing numbers of single or two person households and the rising number of electrical equipment such as dishwashers, microwaves, laundry dryers, computers, etc. Although the electrical efficiency of domestic appliances has improved during the last years the positive effects are counterbalanced by the growing numbers of single households. According to the official statistical data of Baden-Wuerttemberg [STA07b] the population of Stuttgart and Esslingen region will stay relatively constant until 2025 due to continuing net immigration. If there are no considerable improvements concerning the electric efficiency of domestic appliances the electricity demand will at least stay on the same level as today.

A four person household has, however, a comparatively lower electricity demand. The average value calculated with in Germany is 4.500 kWh per year. Assuming that the exemplary passive house is equipped with the most efficient technology the annual electricity demand could be reduced to 1.800 kWh [PHI07] which serves as best practice scenario in the calculations.

7.3.3. Heat demand

The maximum heat demand of a passive house is restricted to 15 kWh/ m^2×a as specified by the *Passiv Haus Institut*. Within the course of a year the demand changes and will still be higher during winter time than during summer. Table 1 shows the distribution of the heat and the electricity demand within the course of the year:

Month	Distribution	
	Electricity	Heating
January	0,12	0,15
February	0,11	0,13
March	0,11	0,12
April	0,08	0,09
May	0,07	0,06
June	0,06	0,03
July	0,05	0,02
August	0,06	0,02
September	0,06	0,04
October	0,07	0,08
November	0,09	0,11
December	0,12	0,15
sum	1	1

Table 1: Distribution of electricity and heat demand of a passive house

The fuel cell will be operated according to the households' heat demand. In addition to electricity and heat an extra energy demand exists for hot water production. This demand is set to 35 kWh per m^2 and year. When taking the hot water demand into account the total energy demand of the exemplary 100 m^2 passive house inhabited by a four person household amounts to 68 kWh/ m^2×a as shows Table 2.

Size of one house:	100 m^2			Average
		kWh/m^2×year	kWh/year	kWh/day
Room heating and ventilation kWh/m^2×year		15	1500	4,1
Domestic hot water kWh/m^2×year (4 persons, 30 litre, delta t: 40 degree)		35	3500	9,6
Total Heat consumption kWh/year		50	5000	13,7
Electricity consumption kWh/m^2		18	1800	4,9
Total		68	6800	18,6

Table 2: Household energy demand (best case)

If the current electricity demand of 4.500 kWh/ a is taken into account instead of the best practice value of 1.800 kWh/ a the total energy demand would increase to 95 kWh/ m²×a which could serve as worst case scenario for comparison.

7.3. Household energy balance related to a fuel cell

Based on the household's relative energy demand the energy balance of the fuel cell system is calculated for a 0,5 kW fuel cell system. The calculation is based on the best case assumption with respect to the household energy demand. The following figures show the results.

Fig shows the household’s heat demand in relation to the fuel cell’s heat production. From spring to autumn the fuel cell delivers enough heat to meet the household’s demand. During the winter season extra energy needs to be imported to cover the higher demand.

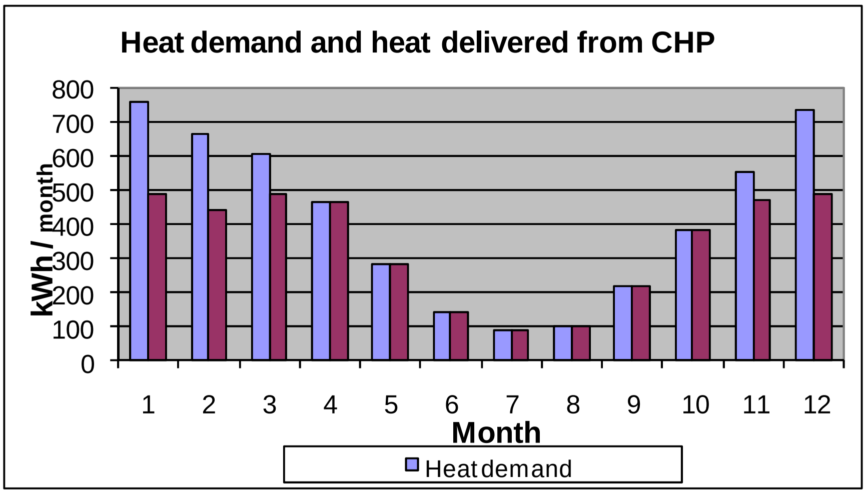


Figure 2: Comparison between the heat demand and the heat delivered from CHP

Due to the German situation electricity would currently be the last choice for space heating. One reason might be the low overall efficiency of electric heating systems in combination with the fact that electricity produced in Germany still comes to vast extends from coal and nuclear power plants. This electricity should be used in the most efficient way, which rules out the electrical heating. With increasing shares of electricity produced from renewable sources this might change. Electric heating might then become attractive as one option for balancing the fluctuating supply from wind or photovoltaic power plants.

A second reason for choosing biomethane over electricity for heating directly depends on the legislation and hence is related to incentives. Whilst the legislation in Denmark for example does not foresee a netexport of electricity into the grid within the annual accounting period and allows the forward and backwards metering of electricity to settle the bill this is different in Germany. There, the current legislation makes it more attractive to sell green electricity to the grid and buy back electricity from the grid to a lower price instead. This way money can be earned. Also, net metering is not common in Germany. As the costs for biomethane or natural gas are lower than the price a household earns from selling electricity to the grid it is even more attractive to use biomethane as additional energy source for space heating.

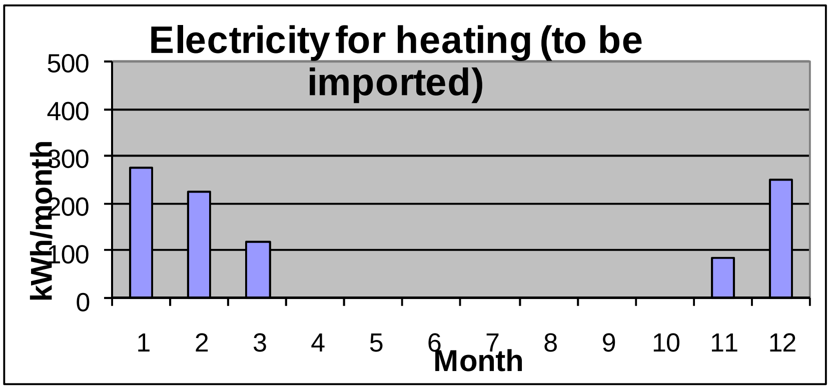


Figure 3: Additional monthly energy demand for space heating

With respect to the household's electricity demand the results are slightly different as Figure 4 and Figure 5 show.

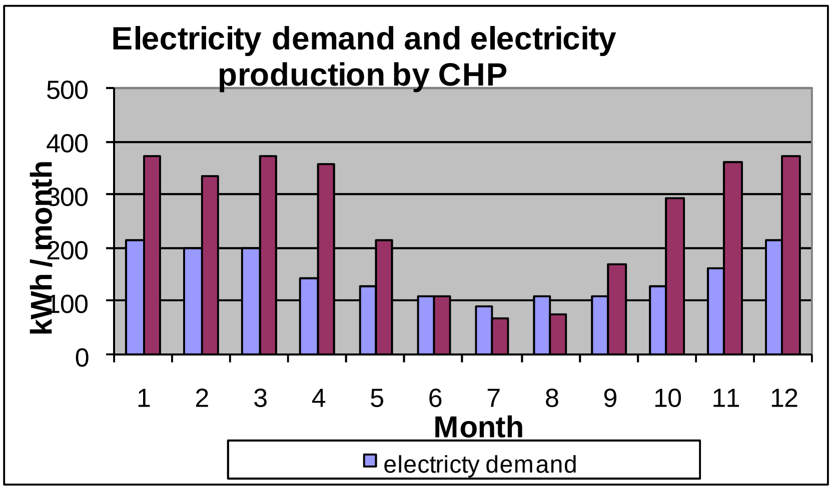


Figure 4: Electricty demand and electricity produced by CHP

In general the coverage is higher than the demand except for one month when the production meets the demand and two month during the summer when electricity definetely needs to be imported.

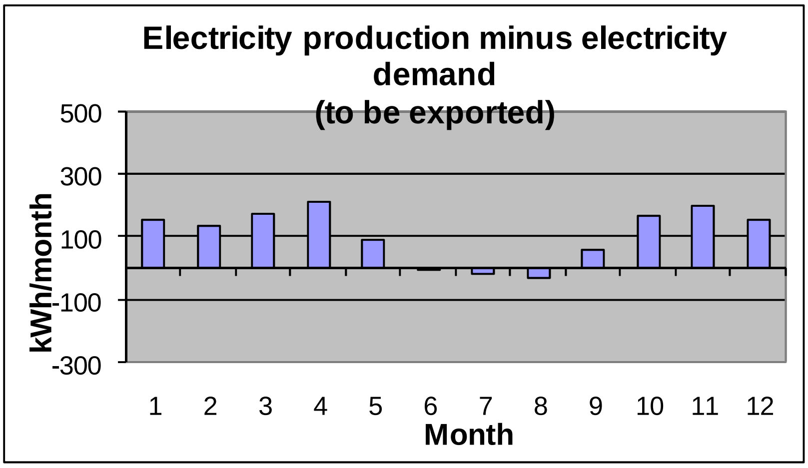


Figure 5: Electricity production minus electricity demand

7.4. Costs for producing bio methane

Raw biogas from agricultural substrates has an average methane (CH_4) content of 53,5 % and methane has a higher heating value (HHV) of 11 kWh/m³. Hence the HHV of the raw biogas can be calculated to 5,8 kWh/ m³. This means that – with respect to the HHV – 1,89 m³ of raw biogas equals 1 m³ of methane. The following cost arise for biogas production, cleaning and upgrading in Germany [FNR06]:

a) production costs for 1 m³ raw biogas = 4,5 ... 5,5 ct/kWh[8]
b) costs for cleaning and upgrading biogas = 1,5 ... 2,5 ct/kWh[9]
c) total production costs for 1 kWh bio methane = 6 ... 8 ct
d) total production costs for 1 m³ bio methane (11 kWh) = 66 … 88 ct = 0,66 … 0,88 €/ Nm³

If mainly energy crops are digested in smaller biogas plants the production costs of raw biogas might increase by 2,5 ct/kWh. Biogas upgrading and injection into the natural gas grid is not economically viable for smaller biogas plants and therefore they are not considered for cost calculations.

Depending on the local conditions natural gas prices can vary between 6-12 ct/ kWh. Most utilities, however, offer natural gas for 6-7 ct/ kWh for end users which is slightly cheaper than bio methane. If grid-injection and transmission costs are taken into account for bio methane the difference increases. All further calculations are based on the following prices of bio methane:

	expensive	cheap	scenarios			
			1	2	3	realistic
Net price of hydrogencarrier used by CHP Euro/ Nm³	0,90	0,60	0,90	0,75	0,60	0,70

Hydrogen production costs

In this scenario hydrogen is produced from bio methane by reforming. The reformer is integrated into the fuel cell appliance and therefore the costs for the reformer are included in the fuel cell household system's price.

The hydrogen production costs vary depending on the bio methane price, the costs for the FCHS (and thus on the number of systems installed), the depreciation period and the amount of taxes imposed on bio methane. For better comparison and to demonstrate the influence of the various parameters the hydrogen price is calculated for four different scenarios:

- Option A1: 10 FCHS, taxes imposed on bio methane
- Option A2: 10 FCHS, no taxes on bio methane
- Option B1: 300 FCHS, taxes imposed on bio methane
- Option B2: 300 FCHS, no taxes on bio methane

Taxes on bio methane include:

- grid payment costs (i.e. costs for distributing the gas within a certain gas grid, long distance transport costs are not taken into account) = approx. 2 ct/ kWh,
- concession charges[10] = approx. 0,61 ct/ kWh,

---

[8] Typical price for which raw biogas is sold by the biogas plant

[9] Typical costs if scrubbing technology is applied

[10] The concession charge is a variable charge and depends on the size of the commune or municipality concerned. The value chosen represents smaller cities such as Esslingen.

- natural gas taxes = 0,55 ct/ kWh
- VAT = 19 %

By taking these taxes into account the resulting costs of the hydrogen carrier vary between 1,06 €/ Nm³ for a cheap bio methane price and 1,42 €/ Nm³ for a more expensive bio methane. If a realistic net price of 70 ct/ Nm³ is taken into account the resulting bio methane costs are 1,18 €/ Nm³. The details including the costs of hydrogen per house and year are provided in *Table 3.*

	expensive	cheap	scenarios			
			1	2	3	realistic
Net price of hydrogen carrier used by CHP Euro/ Nm3	0,90	0,60	0,90	0,75	0,60	0,70
Grid payment per kWh	0,02	0,02	0,02	0,02	0,02	0,02
Grid payment per Nm3	0,22	0,22	0,22	0,22	0,22	0,22
Concession charge per kWh	0,0061	0,0061	0,0061	0,0061	0,0061	0,0061
Concession charge per Nm3	0,067	0,067	0,067	0,067	0,067	0,067
CO2 per Kwh heavy process	0	0				0
CO2 per Nm3	0	0	0	0	0	0
Natural gas tax per kWh	0,0055	0,0055	0,0055	0,0055	0,0055	0,0055
Natural gas tax per Nm3	0,061	0,061	0,061	0,061	0,061	0,061
Sum of tax ex. VAT	0,1276	0,1276	0,1276	0,1276	0,1276	0,1276
VAT % 19	0,17	0,11	0,17	0,14	0,11	0,13
Hydrogencarrier price incl. tax per Nm3, Euro	**1,42**	**1,06**	**1,42**	**1,24**	**1,06**	**1,18**
Costs of hydrogen per house per year ex. depreciation Euro	1.211	906	1.211	1.058	906	1.008

Table 3: Costs of hydrogencarrier including taxes

The “no tax” version simulates a better governmental support for introducing fuel cell systems. The resulting costs of the hydrogen carrier therefore equal the net price of the hydrogen carrier. To determine the full costs of the hydrogen carrier the investment costs of the FCHS and the depreciation period need to be considered. The prices used for the FCHS are the 2009 values provided by Dantherm. If 10 systems are purchased the resulting costs for a 0,5 kW_{el} FCHS are 48.000 € per system. The price decreases to 29.000 € per system, if 300 systems are purchased. Those prices are still higher than the target costs of 10.000 € per kW. The depreciation period is set to five years equalling a lifetime of 40.000 operating hours. For the different options defined above the resulting costs for the hydrogen carrier as well as for the heat and electricity produced are shown in the following sections.

Option A1: 10 FCHS, taxes imposed on bio methane

	expensive	cheap	scenarios			
			1	2	3	ideal
Hydrogencarrier price incl. tax per Nm3, Euro	**1,42**	**1,06**	**1,42**	**1,24**	**1,06**	**1,18**
Costs of hydrogen per house per year ex. depreciation Euro	1.211	906	1.211	1.058	906	1.008
Price of CHP Euro	48.000	48.000	10.000	10.000	10.000	5.000
Lifetime of CHP year	5	5	5	5	5	5
Depreciation of CHP Euro/Nm3 hydrogen carrier	11,25	11,25	2,34	2,34	2,34	1,17
Depreciation of CHP Euro/kWh	1,02	1,02	0,21	0,21	0,21	0,11
Depreciation of CHP per year	9.600	9.600	2.000	2.000	2.000	1.000
Costs of hydrogen carrier per house per year incl. depreciation Euro	**10.811**	**10.506**	**3.211**	**3.058**	**2.906**	**2.008**

The high investment costs and the short depreciation period increase the costs for the hydrogen carrier for one household to almost 11.000 € per year. If costs of 10.000 € per system could be realised the costs would decrease to approx. 3.000 € per year.

Based on these figures, a consumer price for electricity of 0,22 € and a consumer price for heat of 0,07 € (both incl. VAT) the costs related to heat and electricity production with a FCHS are calculated to be as follows:

	expensive	cheap	scenarios			
			1	2	3	ideal
Value of electricity production from CHP Euro	606	606	606	606	606	606
Value of heat production from CHP Euro	283	283	283	283	283	283
Value of CHP production per year	889	889	889	889	889	889
Value of CHP production minus cost of hydrogencarrier	**-9.922**	**-9.617**	**-2.322**	**-2.169**	**-2.017**	**-1.119**
Heatproduction from CHP kWh	4046	4046	4046	4046	4046	4046
Electricity production - net export kWh	2754	2754	2754	2754	2754	2754
Costs related to heat production per year Euro	2610	2536	775	738	701	485
Costs related to heat production Euro/kWh	0,64	0,63	0,19	0,18	0,17	0,12
Costs related to electricity production per year Euro	8201	7970	2436	2320	2205	1523
Costs related to electricity production Euro/kWh	2,98	2,89	0,88	0,84	0,80	0,55

Option A2: 10 FCHS, no taxes on bio methane

If taxes on the hydrogen carrier are neglected the resulting costs and prices are slightly but not considerably lower as the following table shows.

	expensive	cheap	scenarios			
			1	2	3	ideal
Hydrogencarrier price, no tax per Nm3, Euro	**0,90**	**0,60**	**0,90**	**0,75**	**0,60**	**0,70**
Costs of hydrogen per house per year ex. depreciation Euro	768	512	768	640	512	597
Price of CHP Euro	48.000	48.000	10.000	10.000	10.000	5.000
Lifetime of CHP year	5	5	5	5	5	5
Depreciation of CHP Euro/Nm3 hydrogen carrier	11,25	11,25	2,34	2,34	2,34	1,17
Depreciation of CHP Euro/kWh	1,02	1,02	0,21	0,21	0,21	0,11
Depreciation of CHP per year	9.600	9.600	2.000	2.000	2.000	1.000
Costs of hydrogen carrier per house per year incl. depreciation Euro	**10.368**	**10.112**	**2.768**	**2.640**	**2.512**	**1.597**

Even if no taxes are raised on the hydrogen carrier the household still needs to pay more than 10.000 €/ a for purchasing the bio methane and hence the “no tax” option will not be studied further. Therefore it can be concluded that other mechanisms are required to make the application of FCHS more economically interesting.

One option is reduced costs for FCHS if more systems are installed. The effect is shown for the example of Option B1 (300 households including taxes).

Option B1: 300 FCHS, taxes imposed on bio methane

	expensive	cheap	scenarios			
			1	2	3	ideal
Hydrogencarrier price incl. tax per Nm3, Euro	**1,42**	**1,06**	**1,42**	**1,24**	**1,06**	**1,18**
Costs of hydrogen per house per year ex. depreciation Euro	1.211	906	1.211	1.058	906	1.008
Price of CHP Euro	29.000	29.000	10.000	10.000	10.000	5.000
Lifetime of CHP year	5	5	5	5	5	5
Depreciation of CHP Euro/Nm³ hydrogen carrier	6,80	6,80	2,34	2,34	2,34	1,17
Depreciation of CHP Euro/kWh	0,62	0,62	0,21	0,21	0,21	0,11
Depreciation of CHP per year	5.800	5.800	2.000	2.000	2.000	1.000
Costs of hydrogencarrier per house per year incl. depreciation Euro	**7.011**	**6.706**	**3.211**	**3.058**	**2.906**	**2.008**

Cutting down the investment costs by almost 50 % reduces the costs for the hydrogen carrier by approx. 3.000 € which is more significant than omitting taxes.

The effect on the costs related to electricity and heat production is shown in the following table:

	expensive	cheap	scenarios			
			1	2	3	ideal
Value of electricity production from CHP Euro	606	606	606	606	606	606
Value of heat production from CHP Euro	283	283	283	283	283	283
Value of CHP production per year	889	889	889	889	889	889
Value of CHP production minus cost of hydrogencarrier	**-6.122**	**-5.817**	**-2.322**	**-2.169**	**-2.017**	**-1.119**
Heat production from CHP kWh	4046	4046	4046	4046	4046	4046
Electricity production - net export kWh	2754	2754	2754	2754	2754	2754
Costs related to heat production per year Euro	1692	1619	775	738	701	485
Costs related to heat production Euro/kWh	0,42	0,40	0,19	0,18	0,17	0,12
Costs related to electricity production per year Euro	5319	5087	2436	2320	2205	1523
Costs related to electricity production Euro/kWh	1,93	1,85	0,88	0,84	0,80	0,55

Compared to Option A1 the costs related to heat production are reduced by approx. 20 ct/ kWh and the costs related to electricity production are reduced by 1 €/ kWh. Both prices are still considerably higher than the average end user costs for heat (7 ct/ kWh incl. tax) and electricity (22 ct/ kWh incl. tax). Even if the system costs are cut down to 5.000 € the costs are still almost twice as high as the average consumer end prices for heat and electricity.

If the system price and the depreciation period is regarded as fix and the consumer price for electricity as variable it is possible to calculate the costs at which the fuel cell is economically viable.

		A1			B1		
		expensive CH_4	**ideal**	**expensive electricity**	**expensive CH_4**	**ideal**	**expensive electricity**
Biomethane feedstock price	[€/ Nm³]	0,90	0,70	0,90	0,90	0,70	0,90
Biomethane incl. taxes	[€/ Nm³]	1,42	1,18	1,42	1,42	1,18	1,42
Price of FCHS	[€]	48.000	5.000	48.000	29.000	5.000	29.000
Depreciation period	[a]	5	5	5	5	5	5
Consumer price of electricity incl. tax	[€/ kWh]	0,22	0,65	3,83	0,22	0,65	2,45
Consumer price of heat incl. tax	[€/ kWh]	0,07	0,07	0,07	0,07	0,07	0,07
Value of electricity production from FCHS	[€]	606	1.790	10.601	606	1.790	6.746
Value of heat production from FCHS	[€]	283	283	283	283	283	283
Value of FCHS production per year	[€]	889	2.073	10.884	889	2.073	7.029
Value of FCHS production minus costs of hydrogen carrier	[€/a]	**-9.922**	**65**	**18**	**-6.122**	**65**	**19**

As the table shows the electricity prices need to be increased dramatically for Option A1 and Option B1. In Option B1 this is for example the case, if electricity costs 2,45 €/ kWh including taxes. An electricity price of 0,65 €/ kWh is, however, enough to make a 5.000 € FCHS viable.

7.7. Conclusion

Under the given circumstances bio methane can be produced to costs of 6 ... 8 ct/ kWh without taxes and 9,6 ... 12,9 ct/ kWh with taxes and charges raised on the feedstock. Those prices are higher than the average consumer price for natural gas. They can, however, still be compared to the upper range of current natural gas prices.

Comparative calculations for ten households, 300 households and FCHS costs of 5.000 € showed that the economical viability of a FCHS is hardly influenced by the omission of taxes. The price of the system itself combined with the consumer price for electricity is much more significant for the economical performance of a FCHS. The results show that R&D as well as demonstration projects still have to go a long way before an economic operation of a FCHS can be realised.

8. COST CALCULATIONS FOR WIND/H2 BASED FUEL CELLS IN GERMANY

By Katrin Pietzsch IBBK and Bernhard Schaible, BSA

7.5. The wind-power to hydrogen scenario

One renewable energy source to produce hydrogen from is excess wind power. As KIBZ mentions in their contribution Germany obtains most wind energy in the coastal regions of the North Sea as well as of the Baltic Sea – e.g. in Schleswig-Holstein that shares a coastline with both seas. As suspected, in the northernmost German state 30 % of the electricity originates from wind energy. More than 2.188 windmills with an annual output of 1907 MW make this possible (s. report WP 2/KIBZ). Locally this leads to noticeable fluctuations in power production, which requires some form of grid management. According to ISET[11], a research institute studying amongst others wind energy and its integration into the German electricity grid, Germany currently faces little problems with excess wind energy and switching off wind turbines is hardly required. The main reasons given are the comparably high reliability of the day-ahead wind prognosis, the availability of power plants with adjustable output and the ability to distribute electricity to other areas in case of high wind power feed-ins. Future scenarios and requirements that are related to the increasing share of wind power in the German electricity mix are being studied and elaborated by DENA[12].

In the wind-power to hydrogen scenario the basic figures used are similar to the setup described for the biogas to hydrogen scenario, although the technical infrastructure – e.g. with respect to transporting hydrogen – is different.

As in the biogas to hydrogen scenario two differently sized projects are studied: a project with ten houses installing FCHS and a project where 300 systems are installed. For both projects passive houses are the basis for calculating the household energy demand using the same values as in the biogas to hydrogen scenario.

Under the current German framework conditions related to advancing the hydrogen economy and the application of fuel cell systems all projects should be coordinated with the National Innovation Programme “Hydrogen and Fuel Cells” (NIP) which was introduced in 2006 and has been worked over in 2007. In total the NIP provides funds of 500 Mio. Euro for R&D projects and demonstration projects..All funds are intended to facilitate market-oriented projects. Important criteria for demonstration projects are the aims to increase the system’s reliability and repeatability, to study the pattern of use, to test and to improve installation and maintenance skills of professionals as well as to identify barriers for commercialising FCHS. Of the total funds available altogether 141 Mio. Euro is allocated for demonstration projects with stationary household fuel cell systems.

Since February 2008 “NOW”, the National Organisation Hydrogen and Fuel Cells, is operating. NOW is coordinating Germany’s National Innovation Programme. Among other tasks, NOW administers the funds, is responsible for the fuel cell market development in Germany and is also the contact for demonstration projects. Approaches to develop fuel cell markets in Germany should be integrated into the national programme in order to benefit from available funds and joint forces. This way a project applying 300 FCHS can be realised.

All following calculations are based on a 100 m² passive house inhabited by a four person household.

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[11] Institut für Solare Energieversorgungstechnik an der Universität Kassel
[12] Deutsche Energie Agentur

7.6. System set-up

The wind power to hydrogen scenario requires a completely new infrastructure consisting of a central electrolyser, hydrogen storage tanks and a hydrogen grid to deliver the hydrogen to the households. Details for this scenario have been described in previous Work Packages. As mentioned in the biogas-to-hydrogen scenario, German authorities are not familiar with approving hydrogen grids in a non-industrial context. Also, the relevant legislation does not exist. Therefore this scenario faces additional challenges that needn't to be considered in the previous scenario. Nevertheless those challenges play no role in the further examinations as they require a separate discussion and study.

This scenario also varies from the biogas-to-hydrogen scenario with respect to the energy source for extra space heating. It uses electricity for space heating. In the biogas case it has been argued, that electricity in general is the last choice for space heating in Germany due to the fact that major share of electricity produced still comes from coal and nuclear power plants. One reason for using electricity in this scenario is to keep the set-up simple. Any other energy/ fuel source would fit better into a different technical concept. If gas were considered as fuel source then a fuel cell system operated with gas would be the more suitable system. Any other fuel source requires an additional burner plus storage space, which makes its application in combination with the fuel cell system less attractive.

8.3. Household energy demand

The household energy demand has been described for the biogas to hydrogen scenario. It can directly be applied to this scenario.

8.3.1 Household energy balance related to a fuel cell

Based on the household's relative energy demand the energy balance of the fuel cell system is calculated for a 0,75 kW fuel cell system. The calculation is based on the best case assumption with respect to the household energy demand. The following figures show the results.

Figure 1shows the household's heat demand in relation to the fuel cell's heat production. From spring to autumn the fuel cell delivers enough heat to meet the household's demand. During the winter season extra energy needs to be imported to cover the higher demand.

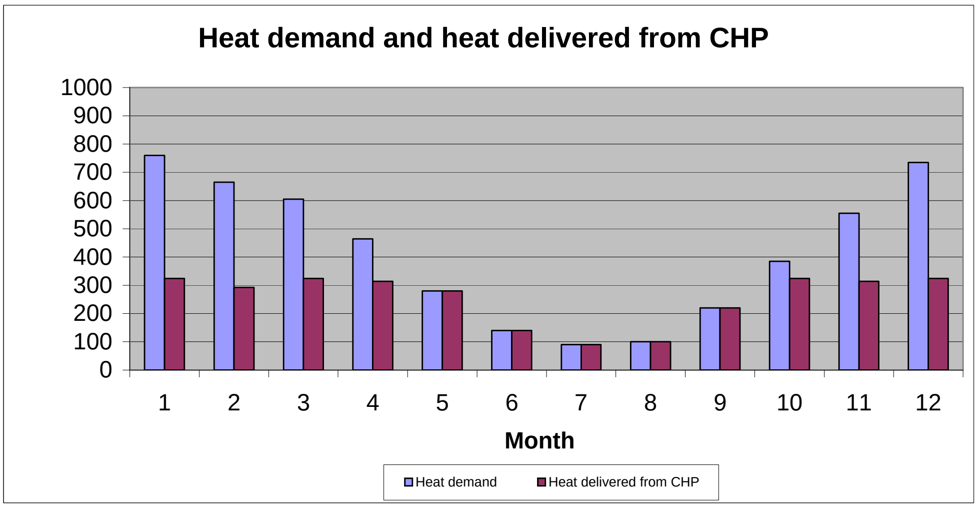

Figure 6: Comparison between the heat demand and the heat delivered from CHP

Figure 2 shows the additional heat demand by month:

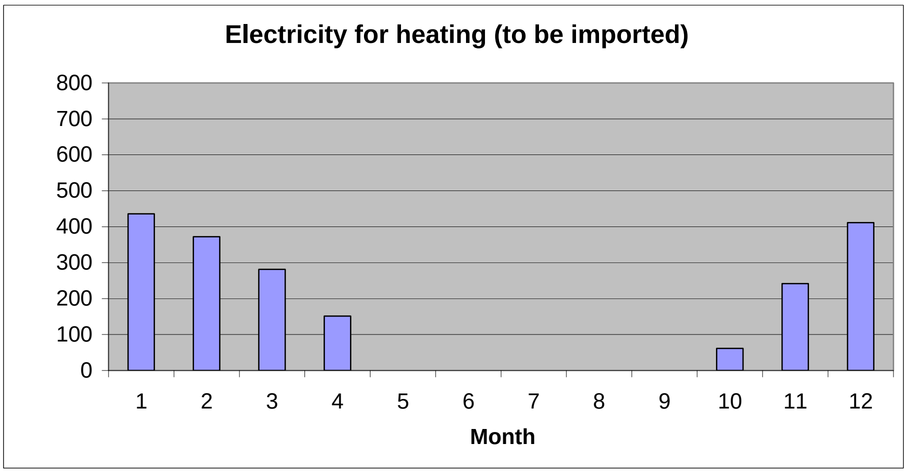

Figure 7: Additional monthly energy demand for space heating

With respect to the household's electricity demand the results are slightly different as Figure 3 and Figure 4 show.

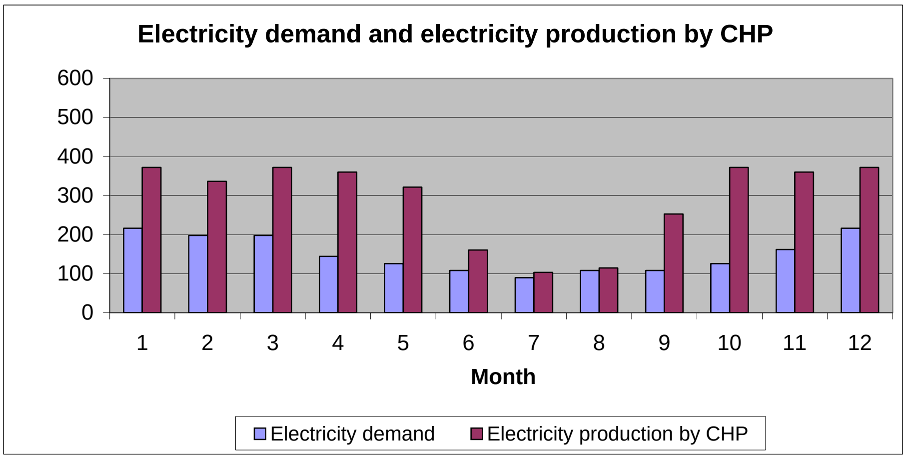

Figure 8: Electricity demand and electricity produced by CHP

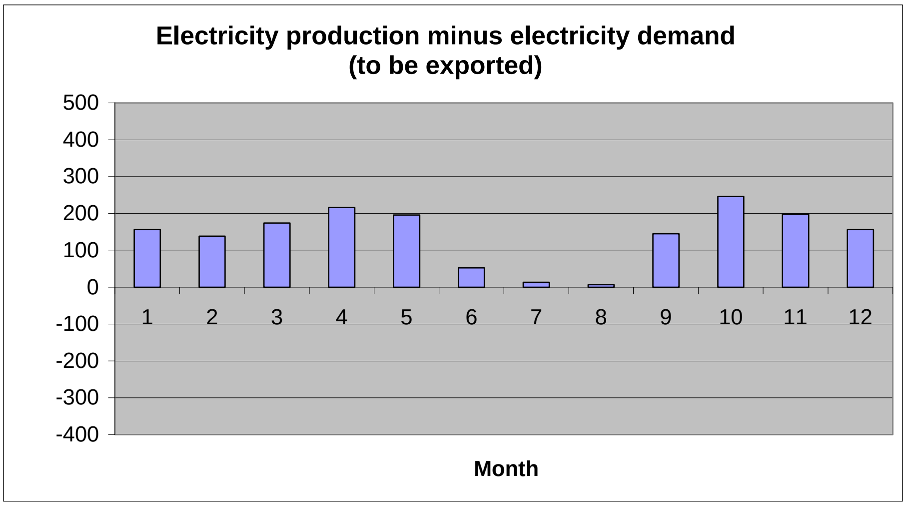

Figure 9: Electricity production minus electricity demand

The electricity produced by the FCHS is not enough to cover the annual demand, especially since electricity is used for space heating. Figure 10 show this.

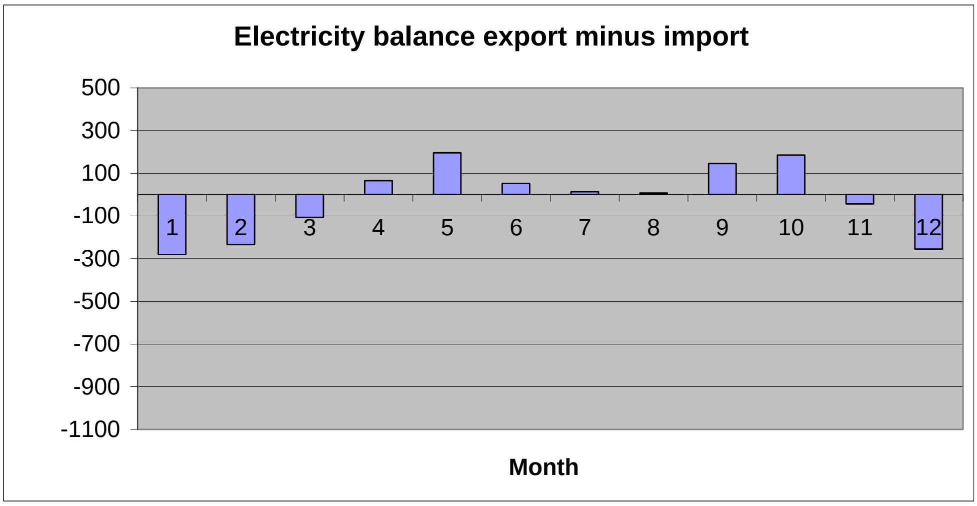

Figure 10: Electricity balance - export vs. import

In total about 300 kWh_{el}/a need to be imported from November to March. At the given consumer price of 0,22 Euro/kWh_{el} the household needs to pay 66 Euro for importing electricity.

8.4. Costs for producing hydrogen from excess wind power

Producing hydrogen by electrolysing water requires a lot of electrical energy and thus electricity prices have a strong influence on the hydrogen price. Therefore the electrolyser is preferably operated during off-peak hours in order to take advantage of low energy prices. For the German context a mean price of 55,83 €/MWh – or 0,056 €/kWh respectively – for off-peak electricity has been calculated based on the base load price for March 2008 provided by the European Energy Exchange (EEX) stock market in Leipzig.

The second factor influencing the hydrogen price is the electrolyser. The more powerful the electrolyser the lower is the specific price per kWh thus reducing the hydrogen production costs. The following table shows the price of hydrogen produced by electrolysis.

Price of hydrogen via Electrolysis:	10 HH		300 HH	
		Euro/Nm3		**Euro/Nm3**
Price of electricity at average off peak time, consumed by the electrolyser , Euro/kWh	0,056		0,056	
Efficiency kWh/Nm3 hydrogen produced	5		5	
Price of electricity at off peak time, used to produce hydrogen, Euro/Nm3 hydrogen		0,28		0,28
Size of electrolyser kW (from calculation)	52		1563	
Price of electrolyser per kW, Euro/kWh (from curve)	8.700		990	
Price of electrolyser, Euro	453.125		1.547.370	
Number of operation hours per day	8		8	
Life time of electrolyser in years	10		10	
Depreciation per kWh consumed by the electrolyser, Euro	0,298		0,034	
Depreciation per Nm3 produced by the electrolyser, Euro	1,04	1,04	0,012	0,012
Maintenance costs		0,0060		0,0060
Price of hydrogen		**1,33**		**0,4**

At the given prices hydrogen could be produced by electrolysis for a price of 1,33 Euro/Nm3 if 10 households are connected to the system. The price sinks to 0,40 Euro/Nm3 for a 300 household system. The price is the net price and does not take into account any additional charges or taxes on hydrogen. Taxes and charges on electricity are, however, included in the electricity price provided by EEX Leipzig.

The final hydrogen price for the end-user is calculated by taking into account grid payment costs to make up for the investment into the hydrogen grid and 19 % VAT. Table 4 shows the resulting end-user prices of 1,68 Euro/Nm3 for 10 households and 0,58 Euro/Nm3 for 300 households respectively.

		10 HH	300 HH
Net price of hydrogen used by CHP Euro/ Nm3		1,33	0,40
Grid payment per kWh		0,02	0,02
Grid payment per Nm3		0,1	0,1
PSO per kWh		0	0
PSO per Nm3		0	0
CO2 per kWh heavy process		0	0
CO2 per Nm3		0	0
Electricity tax per kWh		0	0
Electricity tax per Nm3		0	0
Sum of tax ex. VAT		0	0
VAT %	19	0,25	0,08
Hydrogen price incl. tax per Nm3, Euro		**1,68**	**0,58**
Costs of hydrogen per house per year ex. depreciation Euro		4.083	1.413

Table 4: Costs of hydrogen carrier including taxes

To determine the full costs of the hydrogen carrier the investment costs of the FCHS and the depreciation period need to be considered. The price bases for the FCHS are the 2009 values provided by Dantherm. If 10 systems are purchased the resulting costs for a 0,75 kW_{el} FCHS operated on pure hydrogen are 30.310 € per system. The price decreases to 20.533 € per system, if 300 systems are purchased. Those prices are considerably lower than the prices for fuel cells operated on natural gas. They are, however, still higher than the target costs of 10.000 € per kW. The depreciation period is set to five years equalling a lifetime of 40.000 operating hours. The following sections show the resulting costs for the hydrogen carrier as well as for the heat and electricity produced.

In the first step the investment costs for the CHP as well as its depreciation period are included in the calculation (Table 5).

	10 HH	300 HH
Hydrogen price incl. tax per Nm3, Euro	1,68	0,58
Costs of hydrogen per house per year ex. Depreciation Euro	4.124	1.413
Price of CHP Euro	30.310	20.533
Lifetime of CHP year	5	5
Depreciation of CHP Euro/Nm3 hydrogen	2,47	1,67
Depreciation of CHP Euro/kWh hydrogen	0,71	0,48
Depreciation of CHP per year	6.062	4.107
Costs of hydrogen per house per year incl. depreciation Euro	**10.186**	**5.519**

Table 5: Costs of hydrogen per house per year including investment and depreciation

As a result the households have annual fuel costs of approx. 10.190 Euro if 10 households are supplied and of 5.520 Euro, if 300 households are supplied. If costs of 10.000 € per system could be realised the costs would decrease to approx. 3.400 € per year based on the data for 300 households.

Based on these figures, a consumer price for electricity of 0,22 € and a consumer price for heat of 0,07 € (both incl. VAT) the costs related to heat and electricity production with a FCHS are calculated to be as follows:

		10 HH	**300 HH**
Value of electricity production from CHP	[Euro]	777	777
Value of heat production from CHP	[Euro]	208	208
Value of CHP production per year	[Euro]	985	985
Value of CHP production minus cost of hydrogen	[Euro]	**-9.201**	**-4.535**
Heat production from CHP	[kWh_{th}]	2967	2967
Electricity production - net export	[kWh_{el}]	3532	3532
Costs related to heat production per year	[Euro/a]	2.459	1.332
Costs related to heat production	[Euro/kWh]	0,83	0,45
Costs related to electricity production per year	[Euro/a]	7.727	4.187
Costs related to electricity production	Euro/kWh]	2,19	1,19

The resulting costs for the heat would be 0,83 Euro/kWh_{th} (10 households) or 0,44 Euro/kWh_{th} (300 households. Electricity produced by the FCHS costs 2,19 Euro/kWh_{el} or 1,19 Euro/kWh_{el} respectively. In both cases, the energy produced by the fuel cell costs considerably more than the average consumer price today. The fuel cell becomes economically viable given two general conditions: either the investment costs sink and the lifetime increases or the energy prices rise. In the best case, a combination of both factors lead to positive results. In the 300 household scenario with the 2009 prices for the fuel cell system and the 5 year lifetime this would for example be the case, if the consumer electricity price rises to 1,52 Euro/kWh.

Theoretically feed-in tariffs would be an option to improve the fuel cell's economic performance. Let's assume that in the 300 household scenario the households export all the electricity produced – 3.532 kWh_{el}/a – to the grid and buy back electricity to cover their own demand. Of course they will at least want to cover the costs related to producing electricity with the fuel cell, which is 4.187 Euro/a. The required feed-in tariff to cover those costs is 1,19 Euro/kWh_{el}.

If the household only sells the surplus electricity that is available from April to October – 674 kWh_{el} – the feed-in tariff needs to increase to 6,2 Euro/kWh_{el}, which is beyond discussion.

8.5. Conclusion on hydrogen production from excess wind power

Prices for hydrogen produced from excess wind power have been calculated based on the base load electricity price provided by the electricity exchange market EEX Leipzig for ten and 300 households. If only 10 households are supplied with hydrogen the resulting costs are 1,33 Euro per Nm3 without taxes and 1,68 Euro per Nm3, if a grid payment and VAT are taken into account. If 300 households are supplied the costs decrease to 0,40 Euro/Nm3 and 0,58 Euro/Nm3 respectively. This is considerably cheaper than hydrogen produced from biogas. Nevertheless the total system costs still need to be reduced to make the operation of the FCHS economically viable.

9. COST CALCULATIONS FOR METHANOL/H2 BASED FUEL CELLS IN GERMANY

By Katrin Pietzsch IBBK and Bernhard Schaible, BSA

9.1. Introduction to the methanol to hydrogen scenario

Besides excess wind power and biogas methanol is the third renewable hydrogen source studied in this project. As in the wind-to-hydrogen scenario a central unit – in this case a methanol reformer – produces hydrogen that is delivered to the households via a hydrogen grid. Details for this scenario have been described in previous Work Packages. The remarks on hydrogen grids in non-industrial contexts provided in the tow other scenarios also apply to this scenario.

In contrast to the biogas-to-hydrogen and the wind-to-hydrogen scenarios the methanol-to-hydrogen scenario only looks at the 300 households applying fuel cells. The main reason for doing so is to keep the German methanol case comparable to the Danish methanol case. The basis for calculating the household energy demand is a passive house and the same values as in the other scenarios are applied.

9.2. Household energy demand

The household energy demand has been described for the other two scenarios. It can directly be applied to this scenario.

9.2.1. Household energy balance related to a fuel cell

Based on the household's relative energy demand – i.e. the monthly share of the total annual energy demand – the energy balance of the fuel cell system is calculated for a 0,5 kW fuel cell system. The calculation is based on the best case assumption with respect to the household energy demand. The following figures show the results.

Figure 1 shows the household’s heat demand in relation to the fuel cell’s heat production. From summer to autumn the fuel cell delivers enough heat to meet the household’s demand. During the winter season extra energy needs to be imported to cover the higher demand.

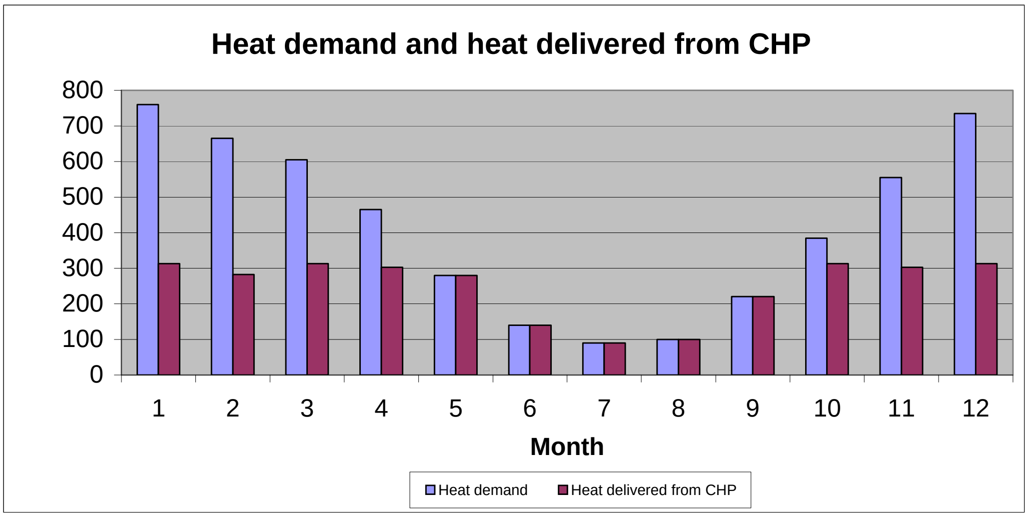

Figure 11: Comparison between the heat demand and the heat delivered from CHP

Which type of fuel or energy is used to cover the extra heat demand depends on the region. Although electricity would hardly be considered in Germany (see biogas-to-hydrogen scenario) this uses electricity for the same reasons described in the wind-to-hydrogen scenario. Figure 2 shows the additional heat demand by month.

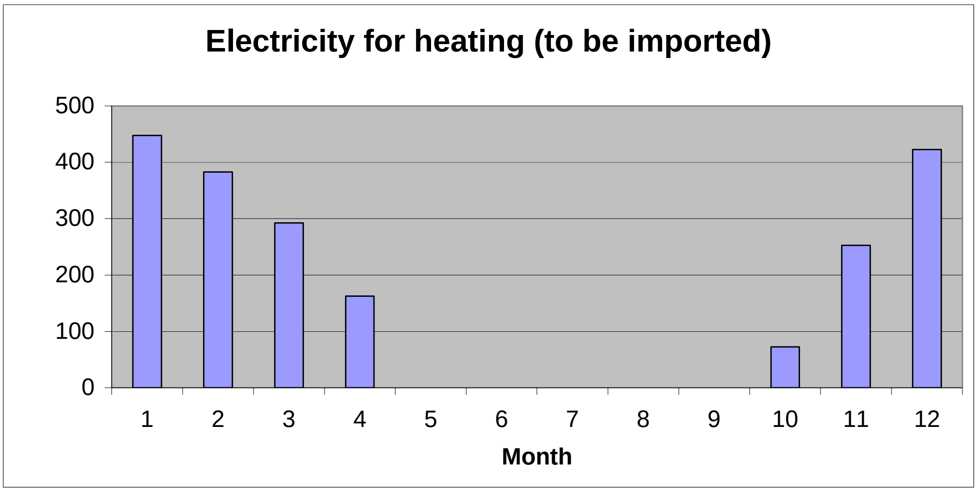

Figure 12: Additional monthly energy demand for space heating

Only from autumn to spring (October to April) the household needs to import energy for heating. During summer the heat produced by the fuel cell is enough to cover the demand.

With respect to the household’s electricity demand the results are slightly different as Figure 3 and Figure 4 show. In contrast to space heating the fuel cell produces enough electricity to cover the annual demand. It would even be possible to export electricity the whole year round, although the amount changes with the seasons. The reason is that the fuel cell is operated according to the heat demand.

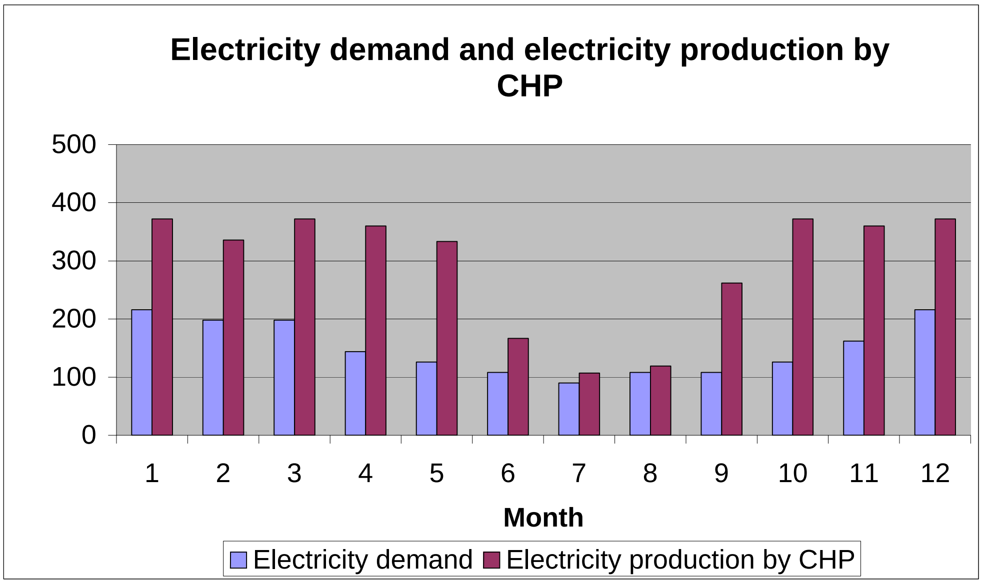

Figure 13: Electricity demand and electricity produced by CHP

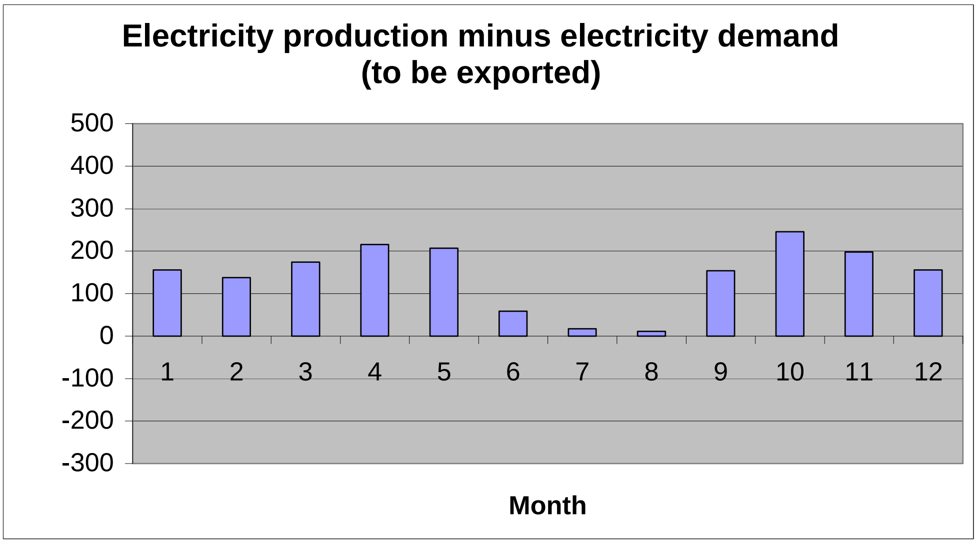

Figure 14: Electricity production minus electricity demand

Although plenty of electricity seems to be available, this does not fully reflect this scenario's set-up. In this scenario electricity is used for space heating. Therefore the electricity demand for heating also needs to be taken into account. Figure 15 shows the household's overall electricity balance.

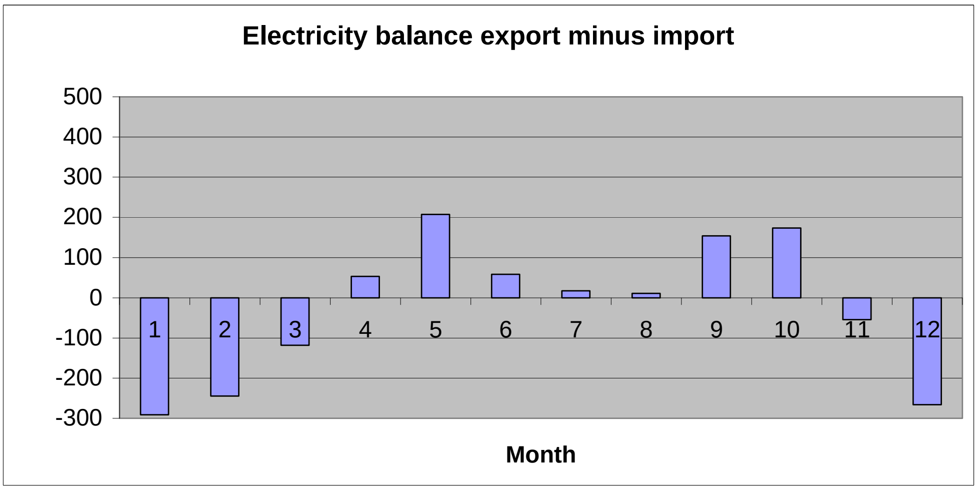

Figure 2: Electricity balance - export vs. import

The fuel cell produces enough electricity to cover both the heat and the electricity demand during seven of twelve months. It is even possible to export electricity to the grid. An import of electricity is required during the remaining five month starting in November. In total more electricity needs to be imported than exported and – based on the annual balance – the household needs to buy approximately 300 kWh from the grid resulting in annual costs of 66 Euro.

9.3. Costs for producing hydrogen from methanol

Methanol is currently mainly produced from natural gas, especially since 2007 when Sustec Schwarze Pumpe GmbH stopped producing methanol from gasifying various kinds of wastes[13]. This scenario therefore calculates with prices for methanol from fossil origin. Methanol prices have been increasing over the

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[13] In some countries the organic fraction of household waste is considered as renewable energy source. Thus hydrogen produced from this waste fraction would be regarded as "green" hydrogen.

last few years. A current price (April 2008) provided by Methanex for the European Posted Contract Price is 295 Euro per ton, which is the basis for further calculation. This is more than twice as much as the price of 110 Euro per ton that was used in the Danish calculation. For Germany we are using the same system set-up and the same hardware costs as in the Danish scenario. The main differences are the prices for electricity and heat that are lower than in Denmark. Both prices (electricity: 22 ct/kWh, heat: 7 ct/kWh) have been used before in the other scenarios.

The second factor influencing the hydrogen price is the reformer. As in the Danish case, a central reformer and thus a central approach has been chosen for this scenario allowing a better comparison of this scenario between the two countries. The sizing and costs of the reformer are the same as in the Danish case with a volume flow of 300 Nm^3 H_2 per hour, investment costs of 2.000.000 Euro and resulting specific investment costs of 6666,67 Euro/(Nm^3*hour).

The following table shows the price of hydrogen produced by reforming methanol. It shows six cases (A-F) for 300 households, but with changing parameters and resulting annual costs or benefits for the household. Cases A and B are basically similar. They apply 2009 prices for 300 fuel cell systems. Variations exist with respect to the fuel cell's lifetime and the consumer price for electricity. Also similar are the cases C and D. Here the fuel cell price is reduced, but the lifetime stays the same. Variations in the consumer price for electricity shows its effect on the overall result. Finally, cases E and F show various variations to illustrate under which conditions a fuel cell operates economically.

Summery of calculations	A	B	C	D	E	F
300 HH						
Reformer cost, Euro/NM3 H2	6666	6666	6666	6666	8000	4000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	295	295	295	295	200	110
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0,20	0,20	0,20	0,20	0,14	0,08
Reformer hardware cost, Euro/Nm3 H2 produced	0,089	0,089	0,089	0,089	0,089	0,053
Net price hydrogen used by CHP (excl. VAT and grid costs) Euro/Nm3 H2	0,29	0,29	0,29	0,29	0,17	0,08
Price of CHP Euro	20.000	20.000	10.500	10.500	10.500	5.000
Lifetime of CHP year	5	10	10	10	10	10
Costs of hydrogen incl. depreciation Euro/Nm3 H2	1,16	0,75	0,56	0,56	0,41	0,20
Costs of hydrogen per year incl. depreciation Euro	5.675	3.675	2.725	2.725	2.012	965
Consumer price of electricity incl. tax, Euro/kWh	0,22	1,20	0,22	0,80	0,22	0,22
Consumer price of heat incl. tax, Euro/kWh	0,07	0,07	0,07	0,07	0,07	0,07
Value of electricity production from CHP Euro	777	4239	777	2826	777	777
Value of heat production from CHP Euro	208	208	208	208	208	208
Value of CHP production per year	985	4.446	985	3.033	985	985
Value of CHP production minus cost of hydrogen, Euro per year	-4.691	771	-1.741	308	-1.027	20

The table shows that under current conditions (case A) the net price for hydrogen produced by reforming methanol is 0,29 Euro/Nm^3, which is considerably lower than the price for hydrogen produced from electrolysis. The net price neither takes into account any taxes on hydrogen nor grid transmission charges or depreciation costs. If VAT and depreciation costs for the CHP are taken into account, the hydrogen price rises to 1,40 Euro. In the end the overall annual balance in case A is negative.

Case B differs from case A in two parameters – the CHP's lifetime and the consumer price of electricity. Both parameters are higher than in case A. In combination the ten-year lifetime and the electricity price of 1,20 Euro/kWh would lead to a positive annual balance.

Cases C and D compare the effect of lower prices for the CHP unit with the influence of high consumer electricity prices on the overall balance. This comparison confirms that decreasing costs for the CHP alone do not automatically lead to an economic benefit for the household. Again only high electricity prices of 0,80 Euro/kWh would turn the wheel and make the operation of a fuel cell economically viable. With today's electricity prices the costs for the reformer and the fuel cell would need to decrease down to 4.000 Euro/Nm^3 H_2 and 5.000 Euro respectively.

9.4. De-central reforming

As in the case for biogas in Germany and Denmark there are a number of arguments speaking in favour of choosing methanol fuelled systems with decentralized instead of centralized reforming. These arguments are:

Choosing decentralized reforming instead we don't have to:

- Build a district heating system in order to utilize the heat from the reforming process – the heat can be utilized directly in the household for domestic hot water or room heating. This will improve the energy efficiency (no loss of heat in the district heating system) and at the same time potentially lower the cost of the overall system.
- Build and pay for a local hydrogen distribution system.

Last but not least it is not necessary to implement the decentralized methanol system in clusters of (new) houses – the systems thus become none disruptive which in a future real market can prove very important. A decentralized methanol based FCHS could become a very relevant alternative to oil fired boilers in existing houses in areas with no district heating or natural gas grids, once the prices come down. But to become a real and attractive alternative it is important that the systems can be purchased and implemented by individual consumers one system at the time, thus avoiding that several hundred consumers has to agree upon purchasing and building a common infrastructure.

When using a 0,5 kWe decentralized methanol fuelled FCHS operated according to heat demand we will end up with an annual net electricity export on approximately 150 kwh - as opposed to a required net import of 300 kWh in the central scenario. The savings on imported electricity actually makes the system marginally cheaper to implement than the centralized reforming solution (without the hydrogen grid savings taken into consideration).

What also can be seen in the table is that the anticipated lower methanol prices in the future only marginally improve the economy of the system. Cost reductions on the CHP and the decentralized reformer are essential in order to move these systems closer to market. The breakeven FCHS price is roughly 3650 Euro (the last column), and looking at the cost curves (WP4.2 paragraph 3.2 page 21) this price can be achieved if 10000 or more units are procured in 2012.

Net price of hydrogencarrier used by CHP Euro/ Nm3/L		0,24	0,09	0,09	0,09
Grid payment per kWh		0	0	0	0
Grid payment per Nm3/L					
PSO per kWh		0	0		
PSO per Nm3/L		0	0	0	0
CO2 per Kwh heavy process		0	0		
CO2 per Nm3/L		0	0	0	0
Electgricity tax per kWh		0	0		
Electricity tax per Nm3/L		0	0	0	0
Sum of tax ex. VAT		0	0	0	0
VAT %	19	0,04	0,02	0,02	0,02
Hydrogencarrier price incl. tax per Nm3, Euro		0,28	0,11	0,11	0,11
Costs of hydrogen per house per year ex. depreciation Euro		533	204	204	204
Price of CHP Euro		25.700	25.700	10.000	3.650
Lifetime of CHP year		5	5	5	5
Depreciation of CHP Euro/Nm3/L hydrogencarrier		2,70	2,70	1,05	0,38
Depreciation of CHP Euro/kWh		0,56	0,56	0,22	0,08
Depreciation of CHP per year		5.140	5.140	2.000	730
Costs of hydrogencarrier per house per year incl. depreciation Euro		5.673	5.344	2.204	934
Consumer price of electricity incl. tax, Euro/kWh		0,22	0,22	0,22	0,22
Consumer price of heat incl. tax, Euro/kWh		0,07	0,07	0,07	0,07
Value of electricity production from CHP Euro		674	674	674	674
Value of heat production from CHP Euro		261	261	261	261
Value of CHP production per year		936	936	936	936
Value of CHP production minus cost of hydrogencarrier		-4.737	-4.408	-1.268	2

The methanol prices used are 295 euro/ton=23,5 eurocent/l, 110euro/ton = 0,09 eurocent/l

9.5. Conclusion

In conclusion the decentralized methanol FCHS is no doubt the most interesting – not due to the marginally better economy at present, but due to the fact that it is more suitable for incremental implementation combined with the higher energy efficiency.

However, the result of the methanol-to-hydrogen scenario confirms the results of the other scenarios: Incentives such as public co funding of the first demonstration projects and in the medium term feed-in tariffs are required in order to make the application of fuel cell household systems economically viable – otherwise the production volume required for reaching the estimated breakeven market price of 3600 Euro in 2012 cannot be achieved.

The most effective way in Germany to support this development will be to use the possibilities that Germany’s new National Innovation Programme Hydrogen and Fuel Cells offers for companies that are on the verge of mainstreaming their fuel cell products.

10. COST CALCULATIONS FOR WIND/H2 BASED FUEL CELLS IN HOLLAND

10.1. Introduction

In task 4.3 of the RES-FC Market project the cost electricity and heat from hydrogen fuelled µ-CHP systems deployed in passive houses in the Netherlands are estimated and compared to present day cost for electricity and heat.

10.2. Calculations

Input from earlier tasks

For the Dutch scenario the following input will be used:

Demonstration size	100 buildings
Hydrogen production	via electrolysis from excess wind
Low cost electricity price	0.059 €/kWh for 1 MW electrolyser
Mean electricity price	0.196 €/kWh for consumers
Mean heating price	0.059 €/kWh for consumers
Feed-in electricity	0.196 €/kWh for consumers (< 3000 kWh)

The energy requirements for the Dutch passive house are estimated as:

		kWh/m2 year	kWh/year
Room heating and ventilation kWh/m2 year		15	1500
Domestic hot water kWh/m2 year (4 persons, 30 litre, delta t: 40 degree)		35	3500
Total Heat consumption kWh/year		50	5000
Electricity consumption kWh/m2		30	3000
Total		80	8000

Background for the input:

The low cost electricity price for a 1 MW electrolyser is the sum of

APX off-peak price	0.029 €/kWh
Transport costs	0.02 €/kWh
Taxes	0.01 €/kWh
Total	0.059 €/kWh

The only possible tariff exemption in a demonstration phase would be the taxes, and the government can define exemptions, since the other costs are from private companies.

The mean electricity and heating price are obtained from WP2.
The feed-in electricity price can be the same as the electricity price paid by the consumer if less than 3000 kWh and only up to the amount purchased by the consumer is fed back into the grid.

By definition, a passive house will require max.15 kWh/m2/year for room heating and ventilation. The domestic hot water and the electricity demand are reduced by approx. 20% compared to the present mean demand.

The heat produced by the electrolyser is not used and has therefore no value.

Results from the spreadsheet calculations:

A spreadsheet is provided by HIRC for calculating the total cost of the fuel cell µ-CHP option using hydrogen as fuel.

The cost of hydrogen at the electrolyser is calculated as 0.54 €/Nm3, see table.

Price of hydrogen via Electrolyses:		Euro/Nm3
Price of electricity at average off peak time, consumed by the electrolyser , Euro/kWh	0.059	
Efficiency kwh/Nm3 hydrogen produced	5	
Price of electricity at off peak time, used to produce hydrogen, Euro/Nm3 hydrogen		0.30
Size of electrolyser kW (from calculation)	469	
Price of electrolyser per kW, Euro/kWh (from curve)	2000	
Price of electrolyser, Euro	938,000	
Number of operation hours per day	8	
Life time of electrolyser in years	10	
Depreciation per kWh consumed by the electrolyser, Euro	0.068	
Depreciation per Nm3 produced by the electrolyser, Euro	0.24	0.24
Maintenance costs		0.0060
Price of hydrogen		0.54

The electrolyser input data in the spreadsheet are provided by BIC. The fuel cell input data are provided by Dantherm. Here the data for an aggregated market of 1000 units in 2011 are used for the base case (10.000 €/kW for a 1 kW system). The fuel cell system size is chosen as 0.75 kWe. In this way 271 kWh net electricity is imported on an annual basis.

The heat demand profile used is shown in Figure 16:

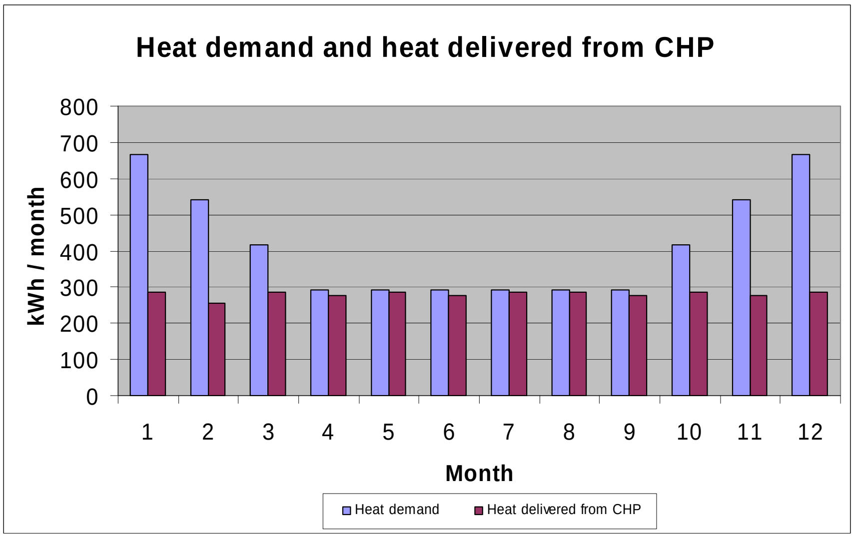

Figure 16: Heat demand and heat delivered by the fuel cell µ-CHP unit.

In the calculation of the yearly costs of the electricity and heat produced by the µ-CHP system, the cost of the µ-CHP fuel cell system, the lifetime of the system and tax exemption for the electricity for the electrolyser are varied and compared to the basic system using the data from Dantherm. These results are shown in the next table.

		Basis	Lifetime	µ-CHP cost	Tax exemption	No investment
Net price of hydrogen used by CHP	€/Nm3	0.54	0.54	0.54	**0.49**	**0.30**
Grid payment	€/Nm3	0.10	0.10	0.10	0.10	**0.00**
VAT %	19	0.10	0.10	0.10	0.09	0.06
Hydrogen price incl. tax	€/Nm3	0.74	0.74	0.74	0.68	0.36
Costs of H2 per house excl. depreciation	€	2,063	2,063	2,063	1,897	992
Price of µ-CHP	€	11,765	11,765	**5,882**	11,765	0
Lifetime of µ-CHP	yr	5.0	**10.0**	5.0	5.0	5.0
Depreciation of CHP	€/Nm3	0.85	0.42	0.42	0.85	0.00
Depreciation of CHP	€/kWh	0.24	0.12	0.12	0.24	0.00
Depreciation of CHP per year	€/yr	2,353	1,176	1,176	2,353	0
Costs of H2 per house incl. depreciation	€/yr	4,416	3,239	3,239	4,250	992
Consumer price of electricity incl. tax	€/kWh	0.196	0.196	0.196	0.196	0.196
Consumer price of heat incl. tax	€/kWh	0.059	0.059	0.059	0.059	0.059
Value of electricity production from CHP	€/yr	833	833	833	833	833
Value of heat production from CHP	€/yr	212	212	212	212	212
Value of CHP production	€/yr	1,045	1,045	1,045	1,045	1,045
Value of CHP production minus cost of H2	€/yr	-3,370	-2,194	-2,194	-3,205	54
Heat production from CHP	kWh	3600	3600	3600	3600	3600
Electricity production - net export	kWh	4250	4250	4250	4250	4250
Costs related to heat production	€/yr	1022	749	749	983	229
Costs related to heat production	€/kWh	0.28	0.21	0.21	0.27	0.06
Costs related to electricity production	€/yr	3394	2490	2490	3267	762
Costs related to electricity production	€/kWh	0.80	0.59	0.59	0.77	0.18

In the base case, a yearly subsidy of 3370 € is necessary in order to compete with the present standard solution using the electricity grid and natural gas grid. Even if the hydrogen would be for free, the cost of the µ-CHP system should be halved or the lifetime doubled for the depreciation of the system to be comparable to the yearly electricity and gas costs. The effect of the tax exemption on the electricity purchase for the electrolyser is approximately 5% reduction of the yearly costs. This is insufficient as a single stimulation measure.

On the other hand, the cost of hydrogen is already higher than the cost of heat and electricity supplied separately by present utilities.

Only in the case that the investment costs for the electrolyser as well as the µ-CHP fuel cell system are neglected, the cost of the heat and electricity service provided by the hydrogen fuelled µ-CHP system are comparable to the separately purchased electricity and heat.

10.3. Conclusion

The heat and electricity demand profile for passive houses in the Netherlands is provided. The cost of the heat and electricity service provided by the hydrogen fuelled µ-CHP system is approximately 4 times the cost of the separately purchased electricity and heat using the estimated efficiency and investment costs for 2011 for 100 buildings in an aggregated market of 1000 units. The investment costs of the µ-CHP fuel cell system, the hydrogen grid and the electrolyser should be fully subsidized in order to have the cost of the heat and electricity service provided by the hydrogen fuelled µ-CHP system comparable to the separately purchased electricity and heat for the demonstration phase. This also holds for the commercial phase.

11. COST CALCULATIONS FOR ISOLATED REGIONAL PROJECTS IN SPAIN

By Beatriz Alzueta Ibáñez

11.1. Background

A short summary of findings in WP3 and WP4.2 are detailed below.

Navarre has a big potential in wind energy, however, the development of this renewable energy source is limited due to the capacity for electricity evacuation. As a way to overcoming this limitation, we could increase the energy consumption during the nights, allowing a larger share of wind power in the network, producing hydrogen by means of using an electrolyser and using the hydrogen in a 1kW CHP PEM fuel cell to produce heat and electricity in the household, during the days.

In spite of the technology being available, nowadays is not a cost-effective option - mainly due to the high investment cost of the system. We know from WP4.2 that mass production of fuel cells will reduce these costs significantly, but this will obviously require a growing and sustained market demand.

The Government has to play an important role in the development of the hydrogen economy and use similar market stimuli as they use to promote the use of other renewable energy sources such as solar energy or biomass.

In Navarra there are two possible locations to carry out a demonstration project. They are named eco-cities (20 houses in each location).

Despite hydrogen technology is available, it is still relative young and unproven. The technology providers cannot yet provide sufficient guaranties to supply ordinary consumers, and furthermore there are legislative issues that have to be resolved regarding the operation of a hydrogen infrastructure.

The Spanish fuel cell manufactures that we have contacted during this study are more interested in automotive sector, so they are developing fuel cells for transport. Therefore in the search for technology providers for our demonstration projects we will have to rely in suppliers from other countries.

Another issue is that at this moment there is no “excess” wind energy, but in Navarra it is likely to become a problem in the near future, because of electrical grid evacuation problems.

There is a general lack of knowledge about hydrogen and fuel cell technologies in the society and from the household promoters and in the pursuit of creating a demand for these technologies it is therefore necessary to disseminate all our knowledge about hydrogen and fuel cells.

We therefore have to acknowledge that it will be difficult to carry out commercialization of these systems in a near future in Navarra. It will be necessary to obtain financial support by the Government for hydrogen technologies in residential sector. Subsidies for demonstration projects could be one way to forward. Also the producers must make a great effort in R&D and initiation of cross border demonstration projects of the systems is required to reduce the cost of these systems by means of a large scale production.

On May 2007 a new legislation (Royal Decree RD 166/2007, May 25) regulates the purchased of surplus electricity supplied by fuel cell systems to the distribution company at a price of 12.04 c€/kWh.

11.2. Discussion of all the numbers and assumptions used for calculation purposes

In this report, the cost of using a 1kW CHP PEM in a household is analyzed. The hydrogen is produced via electrolyses. The system setup is shown in Figure 17.

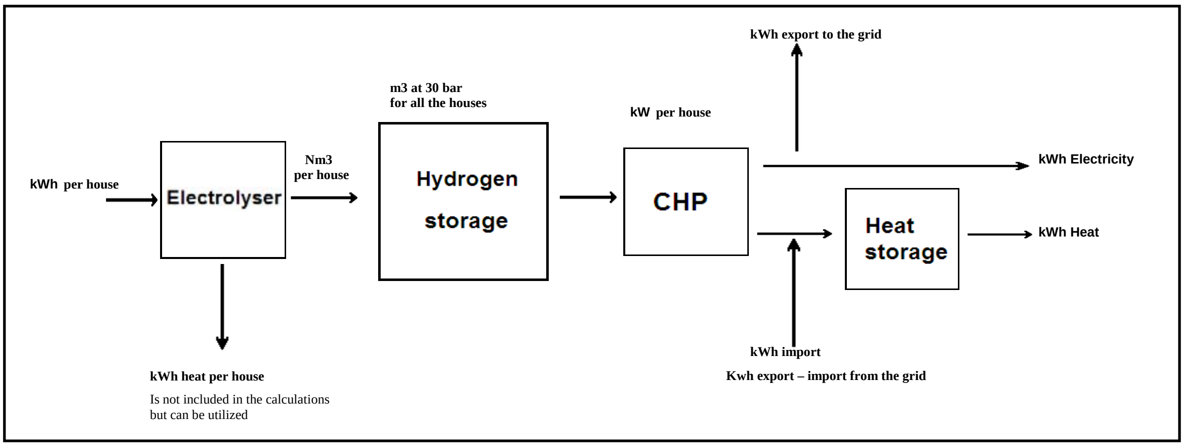

Figure 17. System diagram

Table 6 gives a summary of all the inputs that we have used in the calculations.

As it can be seen in the above mentioned table 2 different scenarios has been used for end user calculation purposes. In case 1 (passive house) the energy consumption in the households are based on data from a European project called passive-on[14]. In case 2 (standard house) the energy consumption is based on actual consumption from a standard house in Navarra. In both scenarios, we have examined two different cases; case A with 20 houses and case B with 100 houses.

Regarding electricity prices, we have taken into account the following aspects for the calculations:

- The electricity price used by end user is according the electricity tariff given in the Royal Decree 871/2007
- The electricity price used by the electrolyser is according to night time spot market price. The price is an average with the cheapest 8 hours (Figure A- 1, Appendix 3).
- The electrolyser works for 8 hours at night, and never runs at the same time that the fuel cell.
- The FC is controlled by the heat demand because the hydrogen costs more than the produced electricity can be sold for.
- If the heat demand is larger than the max possible production from the CHP, then the CHP is operated at its max yield, and the rest of the heat demand is covered by import of electricity.
- If the heat demand is smaller than the max heat yield from the CHP then the CHP is operated at a yield similar to the heat demand.
- Fuel cell efficiencies and prices are based in data facilitated by Dantherm (Figure A- 2 and Figure A- 3)
- We have used a 5 year lifetime for the fuel cell and 20 years for the electrolyser and for all the calculations a 1kW PEM CHP is used.

It is important to notice the huge difference in energy consumptions between a passive and a standard house in Navarra. The electric consumption in a standard house is 70% higher than in a passive house, and the heating consumption is 94% higher, with an average of 78% energy consumption higher.

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[14] http://www.passive-on.org/es/

	PASSIVE HOUSE		STANDARD HOUSE	
	CASE 1A	CASE 1B	CASE 2A	CASE 2B
Number of houses	**100**	**20**	**100**	**20**
Size of one house (m^2)	100		100	
Household inputs				
Room heating and ventilation (kWh/ year)	1,500		6,000	
Domestic hot water (kWh/year)	3,500		2,500	
Total Heat consumption (kWh/year)	**5,000**		**8,500**	
Electricity consumption (kWh/year)	**1,800**		**3,500**	
Total kW/year	**6,800**		**12,000**	
Fuel cell inputs				
Fuel-cell capacity (kW-el)	**1**			
Fuel-cell capacity (kW-th)	0.84			
Fuel cell efficiency (kWh-el/Nm^3)	1.44			
Fuel cell efficiency (kWh-th/Nm^3)	1.22			
CHP energy efficiency	**0.76**			
Price of CHP (€)	22,000	29,000	22,000	29,000
Lifetime of CHP (year)	5			
Electrolyser inputs				
Number of operation hour per day (h)	8			
Price of electricity at average off peak time, consumed by the electrolyser (€/ kWh)	0.0402			
Life time of electrolyser in years	20			
Cost inputs				
Consumer price of electricity incl. tax (€/kWh)	0.093			
Consumer price of heat incl. tax (€/kWh)	0.051			

Table 6. Inputs used to make the calculations.

In Table 7 electricity and heating monthly distribution in the household and fuel cell production is shown. The fuel cell works a maximum of 16 hours per day since the electrolyser and the FC are never run at the same time.

Month	Hours	Max operation hours	Distribution		Demand		Potential production	
			Electricity	Heating	Electricity (kWh)	Heating (kWh)	Electricity (kWh)	Heating (kWh)
January	744	496	0.10	0.18	180	900	496	417
February	672	448	0.09	0.18	162	900	448	376
March	744	496	0.09	0.13	162	650	496	417
April	720	480	0.08	0.13	144	650	480	403
May	744	496	0.07	0.01	126	50	496	417
June	720	480	0.07	0.01	126	50	480	403
July	744	496	0.08	0.02	144	100	496	417
August	744	496	0.08	0.02	144	100	496	417
September	720	480	0.08	0.02	144	100	480	403
October	744	496	0.08	0.02	144	100	496	417
November	720	480	0.08	0.14	144	700	480	403
December	744	496	0.10	0.14	180	700	496	417
sum	**8,760**	**5,840**	**1**	**1**	**1,800**	**5,000**	**5,840**	**4,905.6**

Table 7: Electricity and heating distribution; demand and production by the 1kW CHP PEMFC.

That the fuel cell produce less energy than the potential production (shown in Table 6) it is a consequence of the control strategy (controlled by the heat demand).

11.3. Calculations

Case 1A-B (Passive house)

In Figur (left) is shown the difference between the heat demand and heat delivered from the 1kW CHP PEMFC. As it can be seen, the FC only covers the whole heat demand for 6 months (from May to October).

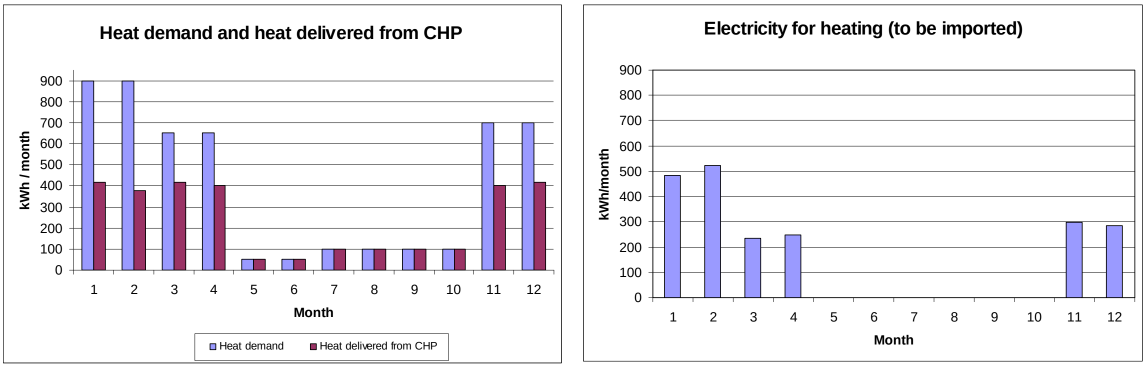


Figure 18: Heat demand and delivered from CHP and electricity imported for heating.

On the right, we can see that during the rest of the months it is necessary to import altogether 2,067 kWh from the grid - 41.34% of the heat consumption.

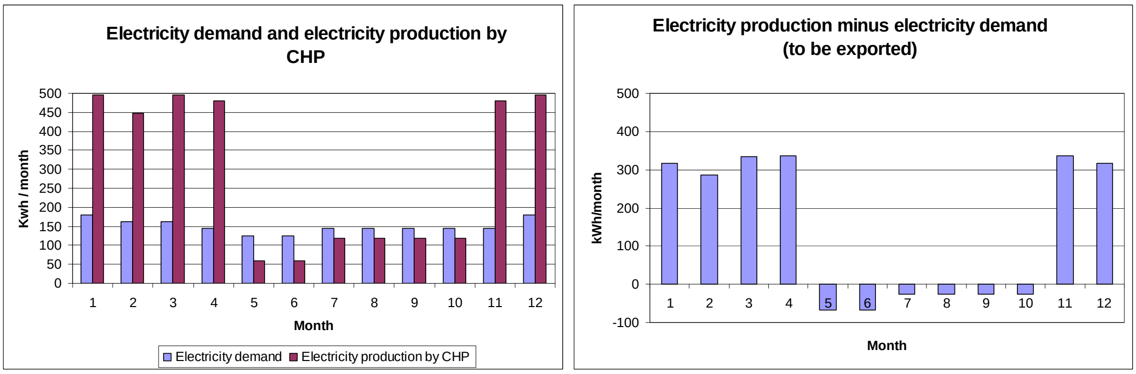


Figure 19: Electricity demand and production by CHP and electricity imported or exported.

Figure 19 shows the difference between the electricity demand and the heat delivered from the FC. Unlike the previous case, between May and October, it will be necessary to import electricity from the grid, 233 kWh. However, during the other 6 months it is possible to sell 1,924 kWh, because of the excess electricity production.

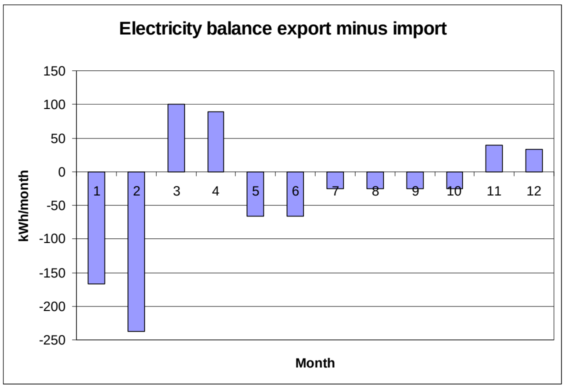


Figure 20. Electricity balance export minus import.

In Figure 20 we can see the balance between the electricity export and import from the grid, but it is necessary to take into account for the economical calculations that the electricity imported is paid by the end user at 0.9 €/kWh, and the exported electricity produced by the fuel cell can be sold at 0.1204 €/kWh (feed in tariff).

An annual 376 kWh is to be imported, but if price is taken into account we achieve the results show in Table 8.

	Electricity to be imported	**Electricity to be exported**
Heating (kWh)	2,067	0
Electricity (kWh)	233	1,924
Total (kWh)	**2,300**	**1,924**
Price (€/kWh)	0.09	0.1204
Total (€)	**207.03**	**231.65**
Profit (€)	**24.62**	

Table 8: Economical calculation between the electricity imported and exported

The total electricity imported is 2,300 kWh (2,067 kWh for heating and 233 kWh for electricity) and the electricity exported is 1,924 kWh.

As it can be seen in the previous table we will profit 24.62 €. by selling the excess electricity.

Case 2A-B (Standard house)

In Figure 21 (left) the difference between the heat demand and the heat delivered from the CHP 1kW PEMFC can be seen. We can see that the FC only covers the whole heat demand for 6 moths (from May to October), the same as in case 1.

As it is shown on the right during the rest of the months it is necessary to import altogether 5,217 kWh from the grid or 61.38% of the heat consumption.

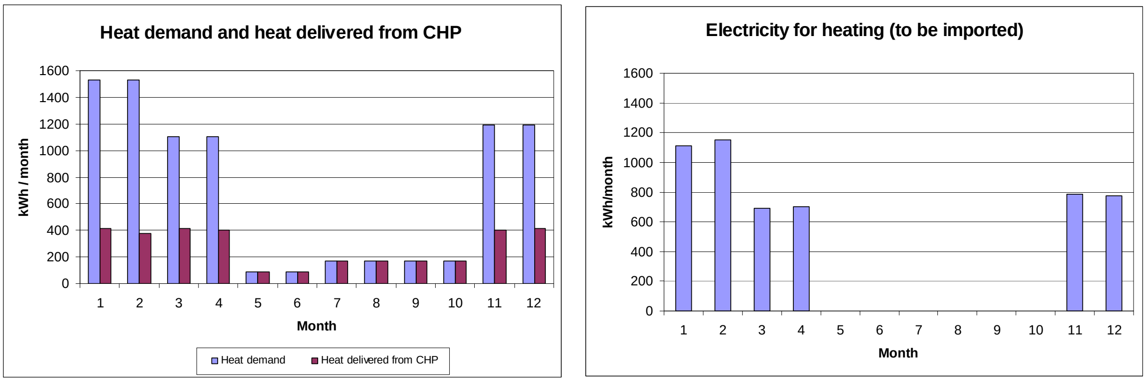


Figure 21. Heat demand and delivered from CHP and electricity imported for heating.

With regards to electrical consumption, as it can be seen in Figure 22, it is necessary to import 1,414 kWh for 6 months, between May and October. During the rest of the months it is possible to sell 598 kWh.

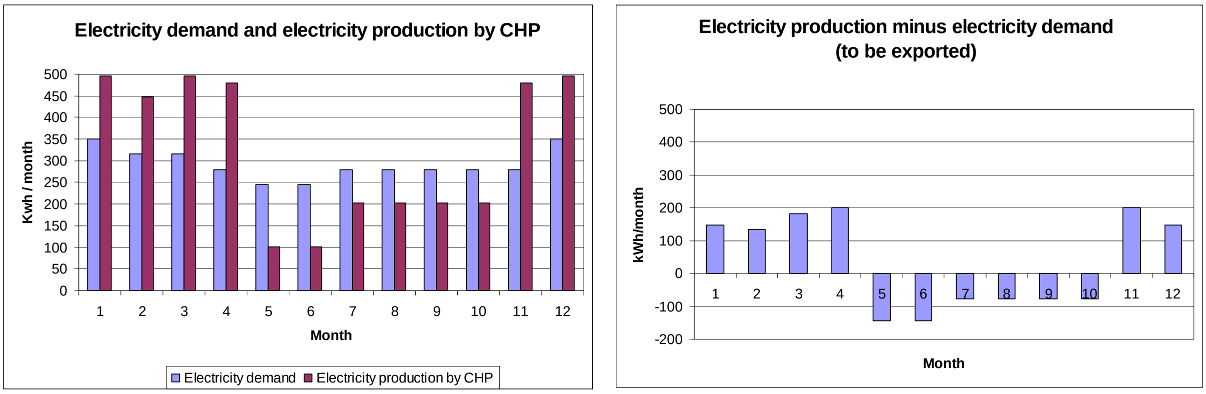


Figure 22. Electricity demand and production by CHP and electricity imported or exported.

If we carry out the balance between electricity imported and exported (Figur), we get a result of 4,809 kWh to be imported to cover the energy demand. This amount is higher that the previous case because the energy consumptions of the household are higher.

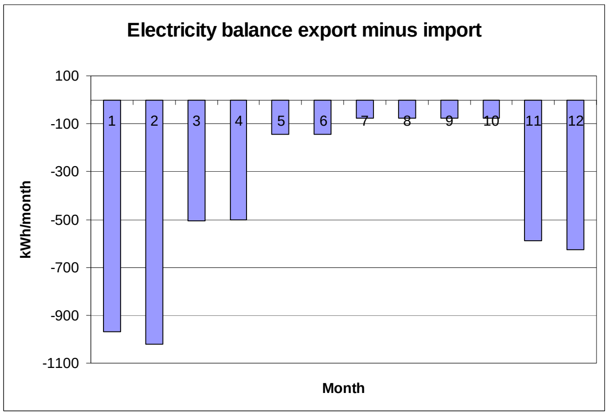


Figure 23. Electricity balance export minus import.

In this case it is necessary to import a large amount of electricity (5,815 kWh) because the heat and electricity demands are really high, and the 1kW FC is too small to satisfy the energy need of the household.

Table 9 shows the results of these economic calculations. In this case, we should pay 402.23€ more, although we get 121.12 € by selling the excess electricity produced by the fuel cell (1,006 kWh).

	Electricity to be imported	Electricity to be exported
Heating (kWh)	5,217	0
Electricity (kWh)	598	1,006
Total (kWh)	**5,815**	**1,006**
€/kWh	0.09	0.1204
Total €	**523.35**	**121.12**
Profit	**-402.23**	

Table 9: Economical calculation between the electricity imported and exported.

From these first analysis we can to conclude that a 1kW fuel cell cannot satisfy the whole energy need of the household, and in case 2 (standard house) the high electricity and heating needs will require a much larger system.

In Table 10 a summary of inputs and outputs are shown, and the overall system energy efficiency.

	PASSIVE HOUSE		STANDARD HOUSE	
	CASE 1A	CASE 1B	CASE 2A	CASE 2B
System input:				
Electricity from wind turbines (kWh / year)	12,122	12,122	13,569	13,569
System outputs:				
Electricity to one house (kWh / year)	1,800	1,800	3,500	3,500
Heat to one house (kWh / year)	5,000	5,000	8,500	8,500
Net to export of electricity (kWh/ year)	-376	-376	-4,809	-4,809
Sum of outputs (kWh / year)	6,424	6,424	7,191	7,191
System energy efficiency	**0.53**	**0.53**	**0.53**	**0.53**

Table 10. System inputs and outputs, and energy efficiency.

11.4. Sizing of electrolyser

The assumptions to calculate the size of electrolyser and the amount of the hydrogen produced by electrolysis are detailed bellow.

As mentioned before, the electrolyser runs for 8 hours per day during the night. It should produce 11Nm^3 H_2 per day per house to satisfy the max demand of the fuel cell (Table 11).

Therefore, the size of the electrolyser depends on the number of houses to supply hydrogen.
In cases 1-2 A (100 houses) it will be necessary an electrolyser of 694kW, whereas in cases 1-2 B (20 houses) the electrolyser will be 139 kW.

It is important to notice that, the more houses in the cluster the more hydrogen storage capacity is required. This parameter has not been taking into account when doing the calculations on the price of hydrogen. Using a storage pressure of 30 bar in 1-2A cases it will be necessary with 37 m^3 storage capacity and 7 m^3 in 1-2B cases.

	CASE A	CASE B
Daily electricity production max. (kWh)	16	16
Fuel cell efficiency (kWh/Nm^3)	1.44	1.44
Daily hydrogen consumption max. (Nm^3)	11	11
Number of operation hour per day (h)	**8**	**8**
Size of electrolyser (Nm^3/h per house)	1.39	1.39
Number of houses	**100**	**20**
Size of electrolyser (Nm^3/h)	139	28
Electrolyser efficiency (kWh/ Nm^3)	5	5
Size of electrolyser (kW)	**694**	**139**
Heat production from electrolyser per house (kWh)	3,042	608
Size of hydrogen storage (Nm^3)	1,111	222
Hydrogen storage pressure (Bar)	30	30
Size of hydrogen storage (m^3)	**37**	**7**
Heat demand per day max. (kWh)	29	49
Domestic hot water per day (kWh)	10	7
Heat storage (kWh)	39	56
Delta temperature 95- 45 (ºC)	50	50
Heat storage (m^3 per house)	0.664	0.967
Yearly hydrogen consumption (Nm^3 per house)	**2,424**	**2,714**
Yearly electricity consumption by electrolyser (kWh per house)	**12,122**	**13,569**

Table 11. Assumptions to calculate the size of the electrolyser

As it can be seen in Table 11 the amount of hydrogen to be used into the fuel cell depends of the household energy consumption, therefore in cases 1-2A we need 2,424 Nm^3 H_2 house/ year with 12,124 kWh per house /year from the electrolyser. In cases 1-2B the hydrogen consumption is 2,714 Nm^3 H_2 per house/ year and 13,569 kWh per house /year from the electrolyser.

11.5. Price of hydrogen via electrolyses

Now, the price of the hydrogen via electrolysis is calculated. Table 12 gives a summary of the calculations performed.

	CASE A	CASE B
Price of electricity at average off peak time, consumed by the electrolyser (€/kWh)	0.0402	0.0402
Electrolyser efficiency (kWh/ Nm^3)	5	5
Price of electricity at off peak time, used to produce hydrogen (€/Nm^3 hydrogen)	0.20	0.20
Size of electrolyser (kW)	**694**	**139**
Price of electrolyser per kW (€/kWh)	1,800	4,500
Price of electrolyser (€)	**1,249,200**	**625,500**
Number of operation hours per day (h)	8	8
Life time of electrolyser (years)	**20**	**20**
Depreciation per kWh consumed by the electrolyser (€)	0.031	0.077
Depreciation per Nm3 produced by the electrolyser (€/Nm^3 hydrogen)	0.11	0.27
Maintenance costs (€/Nm^3 hydrogen)	0.006	0.006
Price of hydrogen (€/Nm^3 hydrogen)	**0.31**	**0.48**

Table 12: Price of hydrogen via Electrolyses

It is important to explain some of the numbers used for the calculations. The price of the electricity purchased for the electrolyser is a night time spot market price (as an average with the cheapest 8 hours).

The electrolyser efficiency is 5kWh/ Nm^3. Taking into account the size of the electrolyser that we have calculated before and the provided curve provided by BIC. The price is 1,800€/kWh for the 694 kW electrolyser and 4,500 €/ kWh for the 139kW electrolyser.

As it can be seen in figure 4 (appendix 3) the electrolyser price per kW deeply decrease as the power increase, from 500 kW and up the price is more constant.

From these input the hydrogen price has been calculated; in cases 1-2A the price will be 0.31 €/Nm^3 and in cases 1-2 B: 0.48 €/Nm^3.

As it can be seen in the previous table, the costs of hydrogen per house and per year decrease when the number of houses increases. This is a consequence of the decrease of the price per kW of the electrolyser that leads to a decrease of the hydrogen price.

11.6. Cost related to heat and electricity production

To finish the calculations, in Table 13 the remaining data used to calculate the cost related to heat and electricity productions are shown.

	PASSIVE HOUSE		STANDARD HOUSE	
	CASE 1A	CASE 1B	CASE 2A	CASE 2B
Net price of hydrogen used by CHP (€/Nm^3)	0.31	0.48	0.31	0.48
VAT 16%	0.05	0.08	0.05	0.08
Hydrogen price incl. tax per Nm^3 (€)	0.36	0.56	0.36	0.56
Costs of hydrogen per house per year ex. depreciation (€)	872	1,350	976	1,511
Price of CHP (€)	**22,000**	**29,000**	**22,000**	**29,000**
Lifetime of CHP (year)	5	5	5	5
Depreciation of CHP (€/Nm^3 hydrogen)	1.81	2.39	1.62	2.14
Depreciation of CHP (€/ kW hydrogen)	0.52	0.68	0.46	0.61
Depreciation of CHP per year (€)	4,400	5,800	4,400	5,800
Costs of hydrogen per house per year incl. depreciation (€)	**5,272**	**7,150**	**5,376**	**7,311**
Consumer price of electricity incl. tax (€/kWh)	0.09	0.09	0.09	0.09
Consumer price of heat incl. tax (€/kWh)	0.05	0.05	0.05	0.05
Value of electricity production from CHP (€)	325	325	363	363
Value of heat production from CHP (€)	150	150	167	167
Value of CHP production per year (€)	474	474	531	531
Value of CHP production minus cost of hydrogen (€)	-4,798	-6,676	-4,845	-6,780
Heat production from CHP (kWh)	2,933	2,933	3,283	3,283
Electricity production - net export (kWh)	3,491	3,491	3,908	3,908
Costs related to heat production per year (€)	1,867	2,532	1,098	2,589
Costs related to heat production (€/kWh)	**0.64**	**0.86**	**0.58**	**0.79**
Costs related to electricity production per year (€)	3,405	4,618	3,472	4,722
Costs related to electricity production (€/kWh)	**0.98**	**1.32**	**0.89**	**1.21**

Table 13. Cost related to heat and electricity production.

All the numbers are based on the previous calculated price for hydrogen via electrolysis. The fuel cell price we have from Figure A-2 facilitated by Dantherm.

Therefore, in case 1A (100 passive houses), the cost related to heat production is 0.64€/kWh, and the costs related to electricity production is 0.98 €/ kWh. However with the same energy demand but only 20 houses (case 1B) the cost related to heat production is 0.86 €/kWh, and the cost related to electricity production is 1.32 €/ kWh. Table 13 show the price for cases 2 A-B as well.

	PASSIVE HOUSE		STANDARD HOUSE	
	CASE 1A	CASE 1B	CASE 2A	CASE 2B
Net price of hydrogen used by CHP (€/ Nm3)	0.31	0.48	0.31	0.48
Costs related to heat production (€/kWh)	0.64	0.86	0.58	0.79
Consumer price of heat incl. tax, (€/kWh)	0.05	0.05	0.05	0.05
Optimal feed in tariff for heat (€/ kWh)	**0.59**	**0.81**	**0.53**	**0.74**
Costs related to electricity production (€/kWh)	0.98	1.32	0.89	1.21
Consumer price of electricity incl. tax (€/kWh)	0.09	0.09	0.09	0.09
Optimal feed in tariff for electricity (€/ kWh)	**0.89**	**1.23**	**0.80**	**1.12**

Table 14: Optimal feed in tariffs for heat and electricity.

Taking into account the consumer price for both electricity and natural gas (for heating) in Table 14 are shown as well as the feed in tariff for heat and electricity necessary for the system to be competitive for the end user.

As it was mentioned before, feed in tariff in Spain to produce electricity through fuel cell is 0.1204 €/kWh, quite far from the feed in tariff calculated in this report, around 0.8-1.2 €/kWh depending on the case. To finish this analysis, Table 15 shows the feed in tariff necessary for making these systems competitive for end consumers on the basis of different fuel cell prices and expected lifetimes.

Price of 1kW CHP (€)	**29,000**	**22,000**	**10,500**	**5,000***	**5,000***
Lifetime of CHP (year	5	5	5	5	8
Costs related to heat production (€/kWh)	0.64	0.64	0.36	0.23	0.18
Costs related to electricity production (€/kWh)	1.32	0.98	0.55	0.35	0.28
Optimal feed in tariff for electricity (€/ kWh)	**1.23**	**0.89**	**0.46**	**0.26**	**0.19**

Table 15. Cost related to heat and electricity according to CHP price and life time.
*Data based on project's objective of cost reductions

It is apparent that a decrease in the fuel cell cost can make these systems competitive without a feed in tariff as high as currently required.

If we implemented fuel cells in 1000 houses (instead of in 20 or 100 houses) the price of fuel cells would decrease to 10,500€/kW.

Nowadays in Spain, photovoltaic energy is provided with a feed in tariff of 0.44€/ kWh. If the Spanish Government promotes hydrogen and fuel cells as the same way as photovoltaic energy and fuel cell price decreases to 10,000 €/kW, systems based on hydrogen can become be cost-effective.

11.7. Conclusions

- In Spain, it would be more interesting to use a larger fuel cell for use in traditional households, or to use the 1kW fuel cell mainly to cover the electricity needs. The remaining heat demand could then be covered with natural gas. In WP3 we said that in Navarra, household promoters think that it would be more interesting to use a $1kW_e+3kW_{th}$ fuel cell.
- The electrolyser price per kW deeply decrease if the power increases, from 500 kW on up the price is more constant.
- The costs of hydrogen per house and per year decrease when the number of houses increases. This is a consequence of the decrease of the price per kW of the electrolyser that leads to a decrease of the hydrogen price.
- Mass production of fuel cells would enable a price reduction, making these systems more competitive and avoiding the need for a feed in tariff as high as currently.

- If fuel cells cost were around 10,000 €/kW and the Spanish Government promoted hydrogen and fuel cells as the same way as photovoltaic energy, this systems can become competitive for the end user.
- It is necessary that the Spanish Government increases support both in terms of legislative reform and financial support (like photovoltaic energy), to enable hydrogen technologies, to reach commercialisation and to establish a sustainable position in the market. Subsidies for demonstration projects can be one way forward.

12. COST CALCULATIONS FOR ISOLATED REGIONAL PROJECTS IN PORTUGAL

by Paula Fonseca

12.1. Introduction

The Fuel Cell technology is still at an early stage at market penetration and needs to be successfully demonstrated in pilot projects to promote its wider application. The apartment building block selected in Centre region in Portugal has 10 units but in the same development there are other 16 similar building blocks in which the same concept can be easily replicated, if suitable financial incentives are provided. However there is a need for political will on this issue, and further incentives are required. One of the most important policies for renewable energy promotion in Portugal, over the last years, has been feed-in tariffs. Recently a new legislation for auto producers entered into force in Portugal (DL nº 363/2007, Nov 2). This law establishes a tarification system applicable to low voltage electricity production installations. This law regulates the activity of low voltage electricity production for own consumption, without the prejudice of the possibility to deliver to the grid or to others, the surplus production. The threshold for the surplus capacity that can be sold to the grid is 150kW. This law only applies to autonomous electricity production equipment that uses renewable primary energy to produce electricity and heat. The feed in tariff for the electricity produced with Fuel Cells that use Wind Power to produce Hydrogen is 455€/MWh, guaranteed during 5 years, for the first 10MW to be connected. After this limit, and for each 10 MW to be connected in each year, the price decreases 5%. Even considering this incentive, there is a need for additional incentives, like tax reductions, attractive financing mechanisms, rebates, etc., to decrease the high investment costs of technology.

As mentioned before, the potential demonstration market in Portugal is composed by 10 houses (flats). These houses are part of new building blocks of three-four bedroom flats that are being constructed by the biggest constructor of the centre region of Portugal, BASCOL – Construção Civil S.A.

The total electricity consumption of a household, with high electricity needs, amount to around 3500kWh per year.. Portugal is a mild weather country, and therefore the heating period is quite short [EDP Distribuição, Report prepared by INESC Coimbra]. Usually, space heating needs last for 4 months and the most important energy sources used for heating are gas (natural gas and propane), wood and electricity. There is not district heating available in Portugal. Typically, electric heating represents 28% of the total electricity consumption in a household in Portugal, representing about 980kWh per year, in the winter season. Electricity consumption for cooling represents 14% of the total electricity consumption in a household, amounting to 490kWh per year. Although air conditioning has been increasing fast in recent years, the penetration rate is still quite low being 10%.

As a common assumption within this project, the domestic hot water requirement is estimated to be 3500 kWh per house and per year for a family of four persons, this value includes losses in pipes and storage tank.

12.2. Discussion of all the numbers and assumptions used for calculation purposes

In this project the control strategy used for the FC is the heat demand. The FC is controlled by the heat demand to maximize energy efficiency and because the hydrogen costs more than the produced electricity can be sold for. The total energy needed for room heating and ventilation is about 980kWh per year, and the remaining electricity needs are 2520kWh per year. Hot water needs are satisfied with other energy source than electricity. Assuming that the domestic hot water for an aggregate of 4 persons per house is about 3500kWh (thermal power) per year, then the total heat demand will be around 4480 kWh per year. In Table 1, the distribution of electricity as well as the distribution of heat among the different months of the year is presented for the centre region in Portugal.

Month	Distribution Electricity	Distribution Heating
January	0.15	0.20
February	0.14	0.18
March	0.12	0.12
April	0.06	0.07
May	0.06	0.03
June	0.05	0.01
July	0.07	0.01
August	0.06	0.01
September	0.06	0.03
October	0.07	0.06
November	0.07	0.11
December	0.09	0.17
Sum	1	1

Table 1: Distribution of heat among the different months of the year

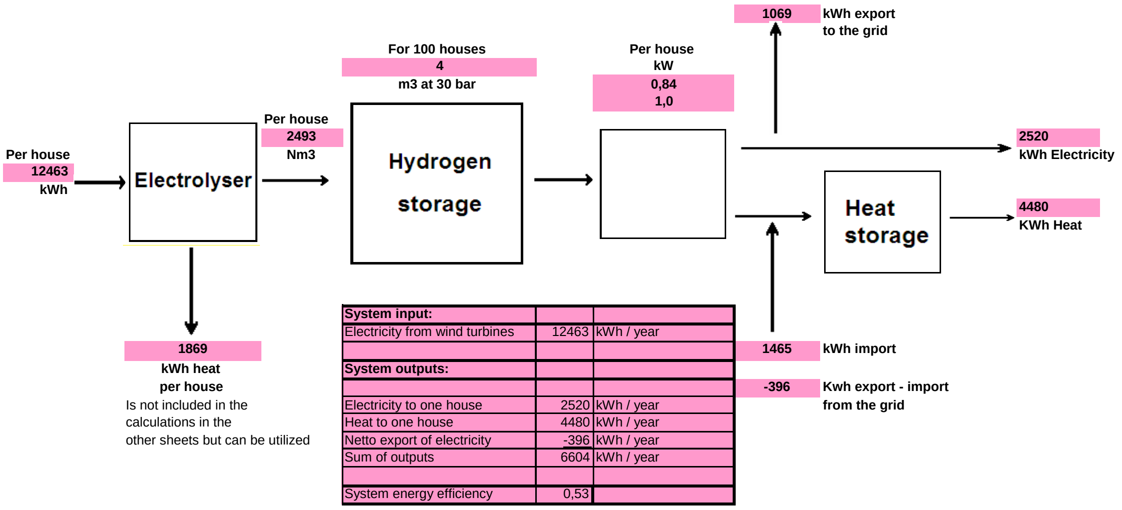
The electrolyser will operate only in the excess wind power generation avoiding the operation during the peak hours where there is no excess of generation and when the electricity cost is higher, so it will operate during the night for a total of 8 hours per day.

The price of electricity for end-users, including taxes, is 0.1131 €/kWh. In Portugal the heat demands are in most cases satisfied with electric equipments so the price of heat, including taxes, is assumed to be the same as the price of electricity. There are other locations where natural gas is used for heating purposes, but these situations are not considered here.

For the calculation of the price of hydrogen via electrolyses it was assumed that it would be applied the Portuguese tariff for final clients in BTN (>27kVA) that have adopted the long use tariff in normal off-peak hours (night tariff). The price of the electricity in these situations is 0.0437 €/kWh.

12.3. Calculations and commenting on calculations

In Figure 1, an overview of the system is presented. The presented values are relative to one house. To produce 2493Nm3 of hydrogen per year for one house, the electrolyser uses 12463kWh of electricity per year. The CHP unit is not sufficient to satisfy the heat and electricity demands of each house. The total electricity that has to be imported from the grid for satisfying the heat demands is 1465kWh per year. The CHP unit can produce more electricity than the demand per house. In theory, about 1069 kWh per year could be sold to the grid but, according to the new micro-generation law, which entered into force on November 2, 2007, (Decree Law nº 363/2007 of November 2), only the excess production is eligible to be exported to the grid. Based on the analysis carried out for the 1 kW Fuel Cell, there is no excess of production. There even is a need to import 396kWh per year. The overall energy efficiency of this system is 53%.



System input:		
Electricity from wind turbines	12463	kWh / year
System outputs:		
Electricity to one house	2520	kWh / year
Heat to one house	4480	kWh / year
Netto export of electricity	-396	kWh / year
Sum of outputs	6604	kWh / year
System energy efficiency	0,53	

1: System info overview

In Figure 2, a comparison between the heat demand and the heat delivered from CHP is presented:

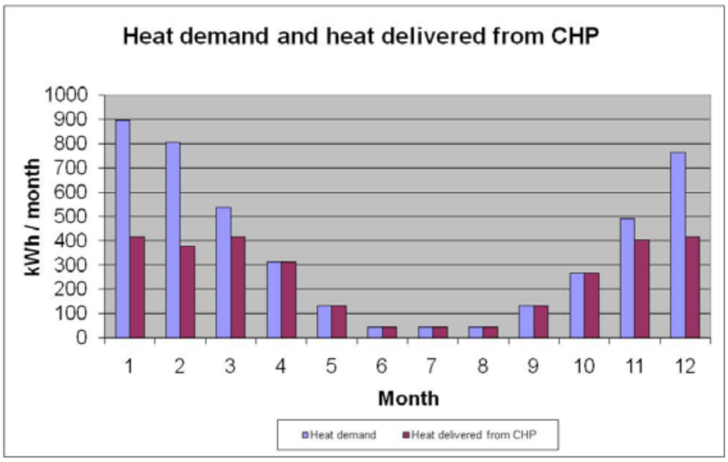


Figure 2: Comparison between the heat demand and the heat delivered from CHP

The heat delivered from the CHP is only sufficient to satisfy the heat demand (heating and water) for 7 moths per year. In Figure 3, the monthly electricity for heating that has to be imported from the grid is presented.During the winter time the amount of electricity that has to be imported from the grid is very high which indicates that the CHP output is very low compared with the needs.

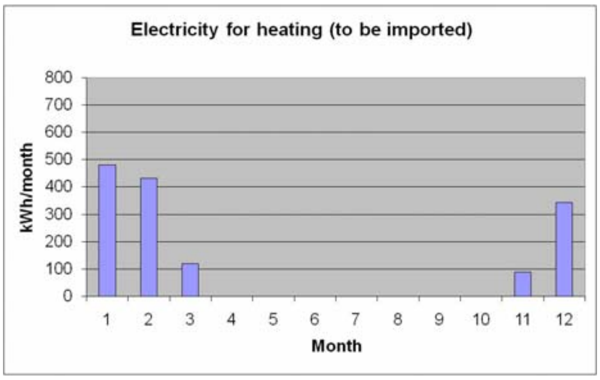


Figure 3: Electricity for heating needed to be imported per month from the grid

In Figure 4, the comparison between the electricity demand and the electricity production from the CHP is presented. It can be seen that the CHP satisfies the total electricity demand for nine months per year.

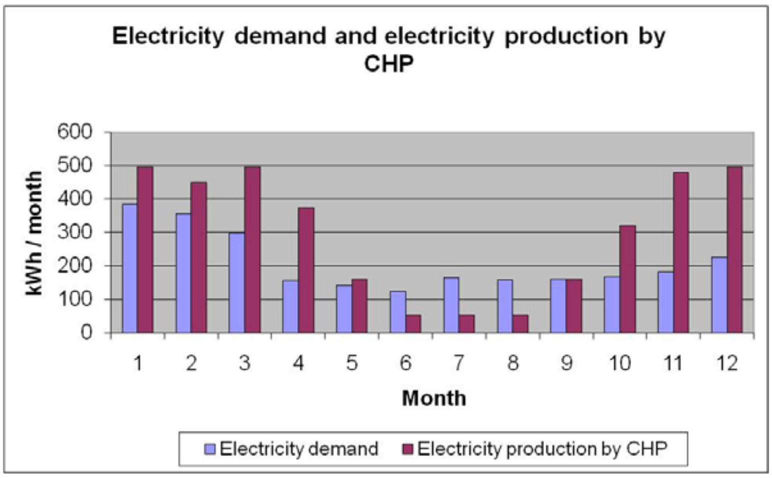


Figure 4: Electricity demand and electricity production by CHP

In Figure 5, the difference between the electricity demand and the electricity production form the CHP is presented.

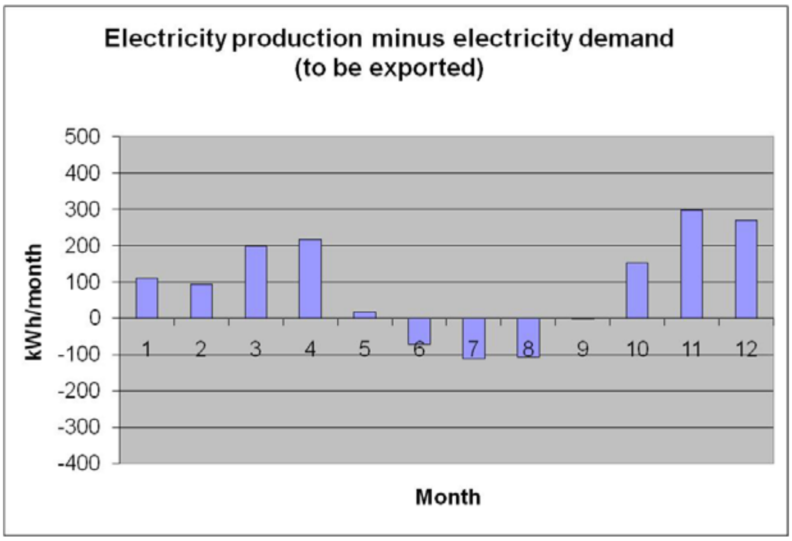


Figure 5: Electricity production minus electricity demand

As it can be seen from Figure 4 and Figure 5, there is only eight months per year when there is some electricity production that could be exported to the grid. The energy needed to be imported from the grid for electricity consumption are significantely lower than the electricity required to produce heat.

In Figure 6, the balance between the total electricity import and export, from the grid, is presented:

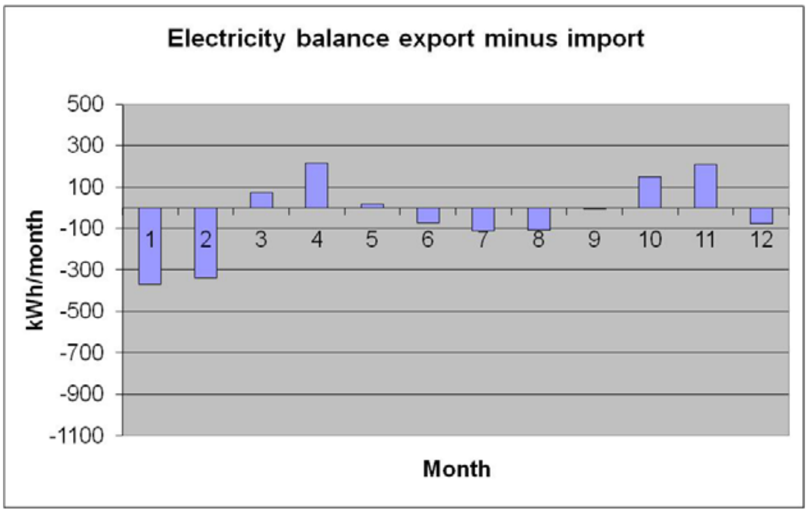


Figure 6: Electricity balance export minus import

Based on the results presented in Figure 6, it can be concluded that there has to be imported electricity from the grid for seven months, especially during winter time because of the higher heating demands. This situation could be improved if a more powerful system is used, instead of a 1kW-el and 0.84kW-th Fuel Cell. Based on the calculation carried out, the price of hydrogen via electrolyses was estimated to be 0.99€/Nm3. This is a very high value compared to the price of electricity. The main reason for this high price is related with the cost of the technology. The price of the electrolyser per kW is around 6400€/kW. According to the power needs of 10 households, the electrolyser is dimensioned for 69kW. The price of electrolyser per KW will deeply decrease for power levels above 200kW. One way to decrease these costs is to increase the number of households, but so far it was not possible to convince additional potential RES-FC users. In Figure 7, the curve that represents the variation of the electrolyser price with power is presented.

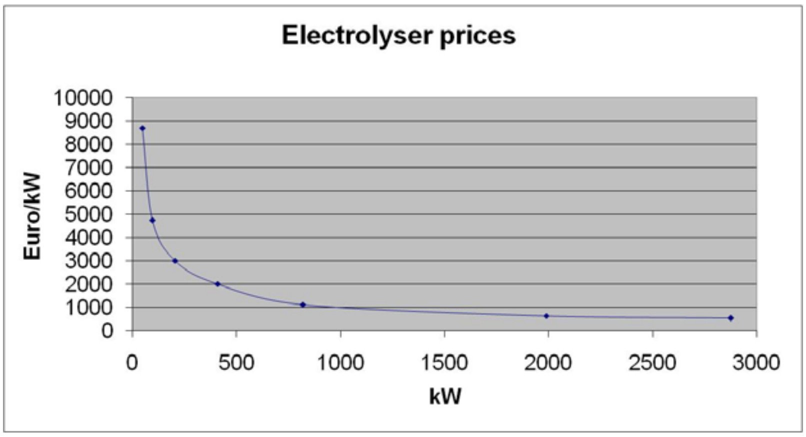


Figure 7: Electrolyser price vs. Electrolyser power

The price of fuel cells is also influenced by the number of houses because it changes with the number of units. This price will be also influenced by the evolution of the technology since it will reduce the production costs of each component of the FCHS. In Figure 8 the learning curves for a 1kW fuel cell with a lifetime of 40000 hours are presented.

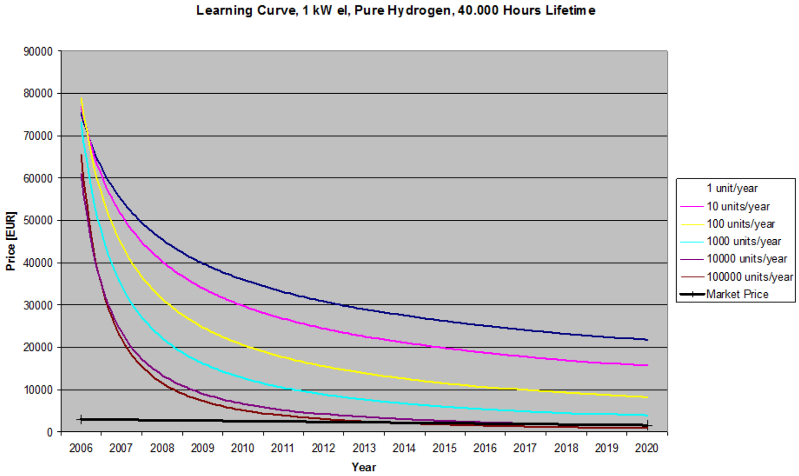


Figure 8: Learning curves for a 1kW fuel cell with a lifetime of 40000 hours

The calculations made have only tacked into account the number of fuel cells for the Portuguese market. If we take into account the aggregated number of houses of the global market the price of the fuel cells will deeply decrease.

According to the price of the hydrogen via electrolyses, the cost related to heat production is 1.75€/kWh and the cost related to electricity production is 1.47€/kWh.

Subtracting in these values the price of the electricity we find the feed in tariff that would be required in order for the system to be attractive for the end user. Therefore, as it is presented in the Table 1, the minimum feed in tariff for heat production would be 1.63€/kWh and for electricity production would be 1.35€/kWh, to make the application economically attractive.

Heat	**Costs related to heat production (€/kWh)**	**Consumer price of heat incl. tax (€/kWh)**	**Minimum feed in tariff (€/kWh)**
	1.75	0.1131	1.63
Electricity	**Costs related to electricity production (€/kWh)**	**Consumer price of electricity incl. tax (€/kWh)**	**Minimum feed in tariff (€/kWh)**
	1.47	0.1131	1.35

Table 1: Feed in conditions for heat and electricity, for 10 households

According to Decree Law no. 363/2007 of November 2, 2007, which brings the possibility to general population to self-produce electricity and sell the excess production to the grid, the feed-in-tariff for the CHP using Fuel Cells and H2 produced from wind power, will be 0.455€/kWh. This feed in tariff is not sufficient to make the system economically attractive for the end user.

Additional simulations have been carried out to estimate the number of houses it would be necessary to push down the costs of the technology that would make the application of Fuel cells economically attractive. For those situations the feed in tariff was calculated. In Table 2, Table 3 and Table 4, the results for 200, 500 and 600 households are presented. As it can be seen in Table 4, even with a total of 600 households, necessary condition to reduce the price of the electrolyser to its minimum possible, the minimum feed in tariff achieved is still higher than the value of the feed in tariff in force under the current legislation, for the electricity produced by FC.

Heat	**Costs related to heat production (€/kWh)**	**Consumer price of heat incl. tax (€/kWh)**	**Minimum feed in tariff (€/kWh)**
	1.08	0.1131	0.96
Electricity	**Costs related to electricity production (€/kWh)**	**Consumer price of electricity incl. tax (€/kWh)**	**Minimum feed in tariff (€/kWh)**
	0.90	0.1131	0.79

Table 2: Feed in conditions for heat and electricity, for 200 households

Heat	**Costs related to heat production (€/kWh)**	**Consumer price of heat incl. tax (€/kWh)**	**Minimum feed in tariff (€/kWh)**
	0.99	0.1131	0.88
Electricity	**Costs related to electricity production (€/kWh)**	**Consumer price of electricity incl. tax (€/kWh)**	**Minimum feed in tariff (€/kWh)**
	0.83	0.1131	0.72

Table 3: Feed in conditions for heat and electricity, for 500 households

Heat	**Costs related to heat production (€/kWh)**	**Consumer price of heat incl. tax (€/kWh)**	**Minimum feed in tariff (€/kWh)**
	0.96	0.1131	0.85
Electricity	**Costs related to electricity production (€/kWh)**	**Consumer price of electricity incl. tax (€/kWh)**	**Minimum feed in tariff (€/kWh)**
	0.81	0.1131	0.70

Table 4: Feed in conditions for heat and electricity, for 600 households

12.4. Wrapping up - including factors speaking in favour of increased competitiveness of FCHS in the future

Fuel Cells are not yet a mature technology and still needs further developments. There is already some equipment available for commercialisation, but at very high prices and low performances, typically 20000 €/kW for PEM fuel cells fuelled by hydrogen. In order to contribute for the fuel cell market deployment, it is important to put in the market FCs at a reasonable price, saying at a few thousand €/kW for PEM fuel cells. [Ref.: Final Report for the EC, Contract Nº 4.1031/Z/02-061/2002, *“Providing energy services with fuel cells in a liberalised energy market”*, February 2005].

Demonstration projects together with the large-scale R&D effort being carried out worldwide to decrease costs and to improve the performance of FC are necessary to lead to the appearance in the market of FC with much lower costs, longer lifetime, and smaller maintenance requirements.

However, in the medium and long term, fiscal and regulatory measures aimed at internalising environmental and social costs within energy prices will be essential for the FC technology to become competitive. One of the most common arguments in favour of FC technologies is environmental protection. As it can be seen in the Figure 9, increased co-generation together with intensifying energy efficiency is one of the most important strategies to reduce greenhouse gas emissions.

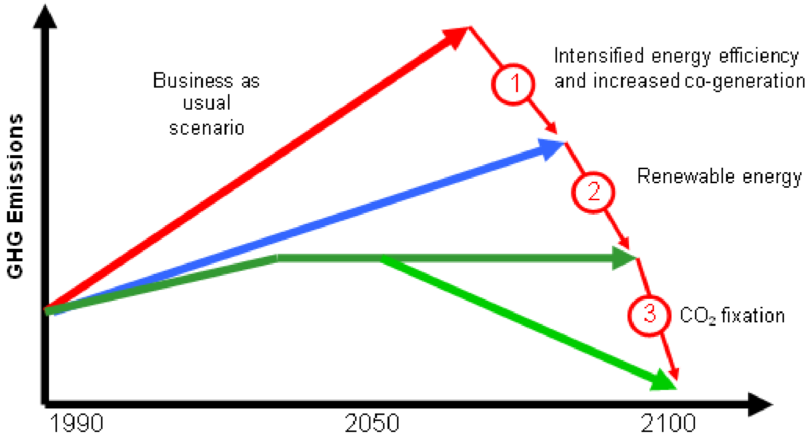


Figure 9: Global Strategies for Sustainable Development

Fuel cell is an ideal technology for decentralized energy production and it has a promising future in households, buildings and also in some small industries applications, either in electricity production or in cogeneration systems. However, a variety of policies and measures to help to overcome the market barriers identified in WP2 is needed. RTD activities are very valuable, particularly demonstration and dissemination activities aimed at overcoming information barriers and increasing consumer confidence. Pilot demonstration projects, together with fiscal incentives and suitable regulatory frameworks, (e.g. tax reductions, financing mechanisms and rebates) can also help to "kick-start" the immature market.

The market research activities carried out in different countries show that national conditions for the introduction and future expansion of fuel cell and CHP energy production are quite different throughout Europe. In order to increase the use of FC in households, and to ensure that national regulations which support Fuel Cells do not contravene with EU competition rules, it is important to identify a European-wide action which is both fair and competitive. In particular, the Electricity, Renewables and the Emissions Trading EU Directives are useful tools to implement such an action. The Commission should revise these directives in order to include a fixed support programme for fuel cells, which will form a kind of European Standard regarding the introduction and future innovation of Fuel Cells.

13. CONCLUSION

As it was described in the introduction to this deliverable: What is important when evaluating the costs of FCHS, is not the cost of the FCHS, but the cost per kWh heat and kWh electricity for the consumer delivered by this system.

Therefore in the pursuit of obtaining cost reductions we have worked on a system level taking into consideration prices of the hydrogen carriers, performed optimization of energy efficiency of the systems looking into different overall system designs, and finally we have looked into the price and requirements for the required reformer units (influencing the hydrogen price). All these factors can potentially improve the end user economy of the systems and thus improve the possibilities of an early as possible commercialisation of FCHS's. The optimization of all these factors was in this report performed locally in each of the regional markets – and calculations on the end user economy was performed as if the demonstration projects were build as isolated regional demonstration projects (without development of an aggregated market).

In WP4.2, regarding the primary fuels renewable methanol and upgraded biogas distributed via the NG grid, it was concluded that what we as FCHS consumers will have to pay the market price for the commodity (methanol and NG) – whether or not the production is subsidized due to its renewable origin. This is the case because the fuels are traded in the world or local market in large volumes and the establishment of joint purchase between a number of regional or European demonstration projects cannot lift our joint demand into a large enough volume to affect the price.

The future large scale availability of the energy sources is in short to medium term, since the production technologies are not yet fully mature and not yet able to compete with fossil fuels (or yet in most cases cost wise with alternative uses of the primary renewable energy source). The availability is also dependant on political will/subsidies. Therefore the availability of the fuels and the development and cost reductions required for the fuel cell systems capable of running on these fuels will have to be handled as two different tasks/pathways that are to run in parallel in the years to come. Using NG or methanol with a fossil origin as a means of getting the market started is in most regions considered the most viable option. This is not the optimum way forward from a renewable energy point of view, but it can improve the energy efficiency and value (electricity is more valuable than heat) of these easily available fuels and is considered the most realistic way forward.

In the wind/H2 scenario there are however some parameters we as project developers can affect in order to optimize the hydrogen price.

As it has previously been described electricity generated by windmills is an integrated part of the current market for electricity, and the introduction of FCHS's can assist in balancing supply and demand in this market. This is an issue that becomes more and more critical/relevant, as we increase the share of fluctuating RES in our energy supply.

We can perform grid balancing by operating our systems according to price fluctuations in the electricity market (which is a consequence of supply and demand). The operation strategy is to purchase electricity and produce hydrogen when the price is low, and run the fuel cells when the price is high. The electricity price is typically low during the night due to low demand. In the first demonstration projects (and for calculation purposes in this report) we run the electrolyser during the night purchasing relatively cheap electricity on the spot market. This optimizes the price at which we can supply our systems with hydrogen. One of the longer term goals of the demonstration projects is to build intelligent operation systems that can make several electrolysers operate in virtual power pools turning on and off the hydrogen production according to the actual electricity price. In virtual power pools the systems can operate in the market for regulation power - taking advantage of the price fluctuations caused by unpredictability of supply (primarily wind but also power plant failures etc.). This give us as system operators a further cost reduction (earning potential) but more significantly (deployed in large scale) it gives room for a very high share of fluctuating renewable energy sources in the electricity supply.

Another thing we can do when setting up our projects is to optimize the size of the household clusters. Remember that when sizing up the electrolyser the price per kW decreases. Above the 1 MW size the price decrease becomes less significant. This implies that the optimum possible hydrogen price today can be obtained by building electrolysers sized to supply clusters between 200 and 600 passive houses (for traditional houses smaller clusters will be suitable due to the higher electricity and heat demand). The cost reduction that can be obtained by sizing up the household cluster is illustrated below.

H2 price H2College	16 houses 80 kW :	1,02 Euro/Nm3
H2 price H2PIA	200 houses 1 MW:	0,33 Euro/Nm3
	600 houses 3 MW:	0,21 Euro/Nm3

In some regions it is not yet, due to economic reasons, possible to establish large FCHS clusters. In these cases it can prove beneficial to establish cooperation with other projects also requiring hydrogen, and thereby increase the hydrogen demand and thus the size of the electrolyser. This can be done by establishing fuelling stations for H2 vehicles in connection to the project, or locating the projects near a company requiring H2 for its production processes.

Regarding optimization of systems efficiency then we can in the wind/H2 projects improve the systems energy efficiency by utilizing the heat from the electrolyser. This can be done by building a local district heating network supplying one or several buildings in close proximity to the electrolyser with heat. Whether or not this is economically feasible is strongly dependant on local conditions. A local district heating network has been built in the Danish H2College project, where the excess heat from the electrolyser is utilized in a large student house. This increases the energy efficiency of the system from 53 to 68% and provides revenue for each house in the cluster of 250 euro/year (before depreciation of the network). For this setup to be economically viable it of course requires close geographical proximity between the electrolyser and the customer for the excess heat.

Until now the overall systems design in the methanol and biogas/NG cases has included a centralized cracker or reforming unit. This was chosen in order to be able to build similar systems (and be able to use the same type of fuel cells) across the 3 hydrogen carriers, and thus pave the way for the development of an aggregated market. After having looked closer at the systems design in the search for possible improvements there are however several arguments speaking in favour of using a decentralized reforming/cracking unit instead. These arguments are valid for both the methanol and upgraded biogas/NG cases:

Choosing decentralized reforming instead we don’t have to:

- Build a district heating system in order to utilize the heat from the reforming process – the heat can be utilized directly in the household for domestic hot water or room heating. This will improve the energy efficiency (no loss of heat in the district heating system) and at the same time potentially lower the cost of the overall system.
- Build and pay for a local hydrogen distribution system.

Last but not least it is not necessary to implement the decentralized methanol system in clusters of (new) houses – the systems thus become none disruptive, which in a future real market can prove very important. In more common words, this mean that the decentralized system can be purchased and implemented by individual consumers one at the time, thus avoiding that several hundred consumers have to agree on purchasing and building a common infrastructure.

A decentralized methanol based FCHS can become a very relevant alternative to oil fired boilers in existing houses in areas with no district heating or natural gas grids, and the biogas system can take market shares in areas with NG grids - once the system prices come down.

Moreover, in the decentralized biogas case the total energy efficiency of the system (28,4% el + 34,5% heat) equalling 62,9% is a significant improvement compared to the traditional method of utilizing biogas. The traditional use of biogas (burning in internal combustion engines) has an efficiency of approximately 40% el, and roughly 20-25% non process heat - which in theory can be utilized externally through a district heating network. However the majority of biogas plants are located far from the urban areas where district heating is used, so in most cases the relevant energy efficiency number to use as a means of comparison is 40%.

With regards to the calculations on the end user economy in the individual regions then it can be concluded, (before the development of an aggregated market), that the prices of electricity and heat for the consumer delivered by the FCHS's is not yet competitive to traditional technologies with the present H2, electricity/heat and FCHS prices in any region under study. The extra cost per year for supplying a household with heat and electricity from a FCHS varies from an extra cost of approximately 2200 Euro per household for 300 houses fuelled by bio methane in Germany to 7200 Euro for 16 houses fuelled by wind/hydrogen in Denmark.

This is far from competitive but what it is very interesting (and promising for the technology) is that the extra cost per household decreases more than 50% (from -7234 to -3444 euro/house) by expanding the project in Denmark from 16 houses (2008) to 200 houses (2009). .

A tax exemption could further improve the economy of the systems in Denmark to have an annual extra cost for the end consumer of app. 3000 euro/year. It is likely that a small segment of green consumers are willing to invest in RES FCHS at this price. However if this technology is to have a major breakthrough it has to become competitive for end consumers. The price at which a FCHS is competitive in Denmark is approximately 2300 euro (without heat utilization of the electrolyser). If a subsidy programme is introduced the breakeven price will off course be higher.

To get the number of demonstration projects initiated - required for the suppliers to reach a production volume large enough, to get the technology pushed to a close to commercial level requires public co funding. When this has been accomplished, it will be required to setup subsidy programmes and or establish feed in tariffs to push the FCHS systems the last way towards commercialisation.

The need for introduction of subsidy programmes for hydrogen technologies has been acknowledged by several governments in Europe e.g. in Denmark and Germany and is likely to be introduced as soon as the technology reaches a price level where such a programme is appropriate.

To get the number of demonstration projects initiated - required for the suppliers to reach a production volume large enough, to get the technology pushed to a close to commercial level requires public co

funding. When this has been accomplished, it will be required to setup subsidy programmes and or establish feed in tariffs to push the FCHS systems the last way towards commercialisation.

A subsidy programme is already in place in Portugal where CHP's using fuel cells and H2 produced from wind power, is given a feed-in-tariff of 0.455€/kWh. This feed in tariff is however not, with the current CHP price, sufficient to make the systems economically attractive for the end user.

From Spain we have the statement that if fuel cells cost were around 10,000 €/kW (within reach) and the Spanish Government promoted hydrogen and fuel cells as the same way as photovoltaic energy, the systems will be competitive for the end user.

As it was anticipated already before having done the calculations, we need to use a larger fuel cell system for the wind-H2 fuelled FCHS than in the biogas and methanol cases. This is due to the fact that the biogas (NG) and methanol fuelled systems can operate 24 hours a day – while the FCHS in the wind case is closed down when the electrolyser is producing H2, and the energy needs of the household in this period are supplied by grid electricity.

When discussing the performance of the energy system it is very important to note that the point of reference, when deciding whether or not to use hydrogen and run the fuel cell, is the heating requirement/possibility of heat storage. This is the case because the overall energy efficiency of the system becomes to low and thus uneconomically, if we don't use the heat generated from the fuel cells. The heat production from the fuel cells can be stored in hot water tanks and directly used for hot water consumption and heating of the household via a ventilation system.

4 persons living in a 100 m2 household house with an energy consumption in accordance with the passive house requirements [PHI07] will in the North European Countries under investigation require a fuel cell system in the size of 0,75 kWe running on pure hydrogen and a 0,5 kWe system running on methanol or upgraded biogas/NG.

In Spain and Portugal where the wind/h2 cases have been investigated the systems size required is bigger than in Northern Europe. We have to implement 1 kWe systems in their passive houses to fulfil their annual heat and electricity needs. This is necessary due to a very different consumption pattern as opposed to Northern Europe. A very short heating season results in relatively few operation hours because of the chosen operation strategy (remember the cells are running according to heat demand).

Since we, when developing an aggregated market, to get the full benefit of the expected cost reductions via to economics of scale, all of us will have to purchase the same basic system. The construction of a modular system seems like the most reasonable way forward. This was looked into in WP4.2 and the preliminary investigations concluded that it would not be an economical solution (due to the complexity of the LT PEM based FCHS). This opportunity will however be looked into again in 4.1.

Apart from the need to develop a modular system in order to be able to achieve the maximum benefit from developing an aggregated market, switching to the use of decentralized reformers/crackers, faces us with a new challenge. LT PEM fuel cells are very sensitive towards impurities such as CO and sulphur, and making small reformers capable of supplying hydrogen of the required purity is very costly. There is however a solution to both of the above mentioned challenges – this will be elaborated on in the next chapter: 4.1

14. APPENDIX ------- APPENDIX 1

Electric consumption in the Passive House 100 m2

Machine	Age / number	Approximate annual consumption	Best alternative
Fridge/Freezer	1 Year	214 kWh	156 kWh
Sum: Fridge/Freezer	Applications: 1	214 kWh	156 kWh
electric cooker		195 kWh	120 kWh
Microwave		85 kWh	
Cooker hood		107 kWh	
Boiler		45 kWh	
Toaster		7 kWh	
Sum: Cooking	Applications: 5	438 kWh	363 kWh
washing machine	8 År	429 kWh	249 kWh
Dish washer		244 kWh	147 kWh
Iron		31 kWh	
Sum: washing	Applications: 3	705 kWh	427 kWh
Colour TV	1 År	307 kWh	
DVD	1 År	50 kWh	15 kWh
Stereo	8 År	89 kWh	63 kWh
Sum: TV/video	Applications: 3	446 kWh	384 kWh
Portable PC (1)		35 kWh	
Portable PC (2)		35 kWh	
Printer		63 kWh	17 kWh
Internet		105 kWh	
Router		105 kWh	52 kWh
Sum: PC	Applications: 5	344 kWh	245 kWh
Energy-saving bulbs		78 kWh	
Strip light		16 kWh	
Sum: lighting	Applications: 2	94 kWh	94 kWh
El toothbrush		14 kWh	1 kWh
Mobile phone (1)		10 kWh	1 kWh
Mobile phone (2)		10 kWh	1 kWh
Sum: appliances with charger	Applications: 3	33 kWh	3 kWh
Vacuum cleaner		31 kWh	
Hair dryer		8 kWh	
Clock radio		70 kWh	
Sum: Other appliances	Applications: 3	109 kWh	109 kWh
Sum		**2.383 kWh**	**1.781 kWh**

The best alternative is below 18 kWh/m2 year which is stated in PHHP 2007

APPENDIX 2

Haldor Topsoe Methanol cracker:

Nominal Size: 300 Nm^3 H_2 /hr (Suitable for 600 houses)
Fully automated operation from 30-100% of rated capacity

Scope of supply:

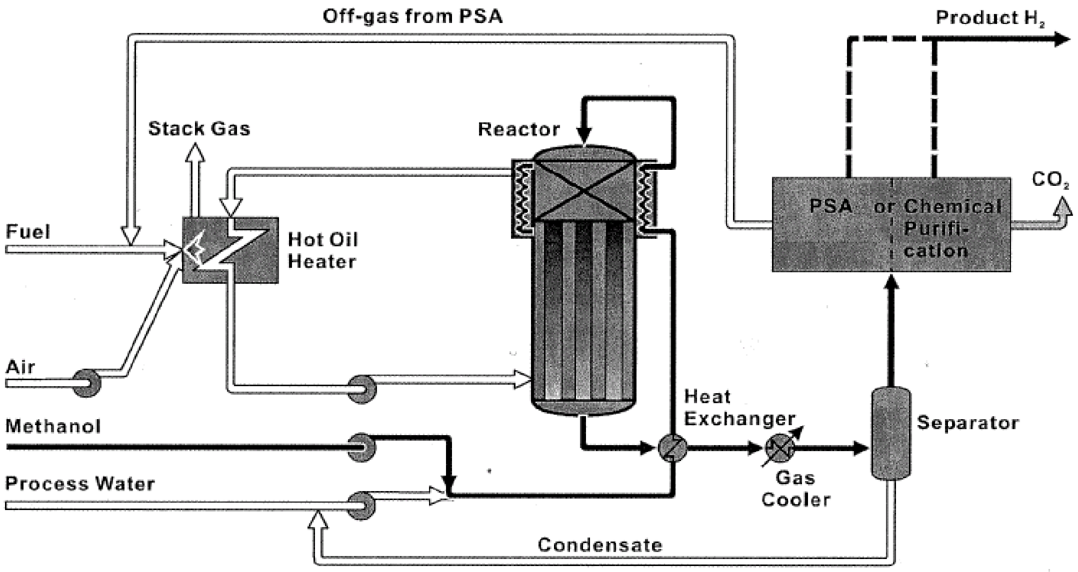
1. Process flow sheets
2. P&I 's
3. Equipment drawings
4. Instrumentation data
5. Material and equipment certificates
6. Operating manual
7. list of spareparts

Expected Main consumption figures for 300 Nm^3 H_2/ hr:

1.	Methanol, 99.99%	approx.	189 kg/hr
2.	demineralized water	approx.	111 kg/hr
3.	Fuel, Methanol	approx.	10 kg/hr
4.	Electricity	approx.	18 KW
5.	Cooling water	approx.	6 kg/hr

Approx. Main Dimensions, with x depth x height, meters:

1.	Methanol decomposition unit	2.6 x 2.6 x 12
2.	Control container	12.2 x 2.4 x 2.4
3.	PSA unit	2.5 x 2.6 x 2.5



Hydrogen production price, from methanol

Reformer cost, Euro/NM3 H2	9000	9000	9000	9000	9000	9000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	400	350	300	250	200	150
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0,27	0,24	0,20	0,17	0,14	0,10
Reformer hardware cost, Euro/Nm3 H2 produced	0,117	0,117	0,117	0,117	0,117	0,117
Net price hydrogen used by CHP (excl h2 grid contribution) Euro/Nm3 H2	0,39	0,35	0,32	0,29	0,25	0,22

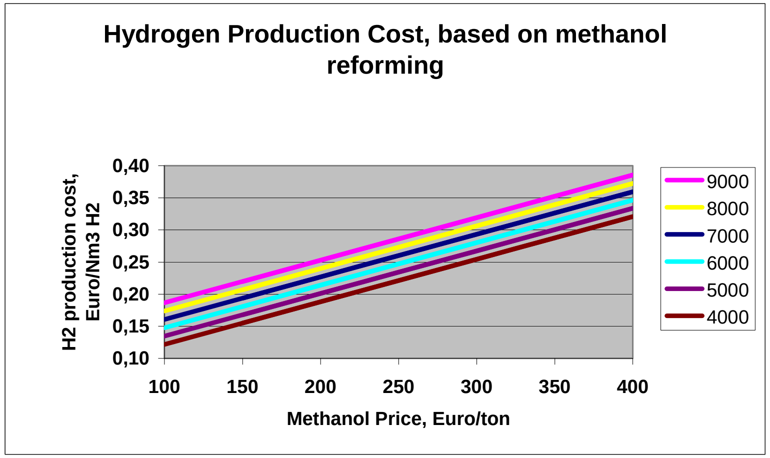
Reformer cost, Euro/NM3 H2	8000	8000	8000	8000	8000	8000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	400	350	300	250	200	150
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0,27	0,24	0,20	0,17	0,14	0,10
Reformer hardware cost, Euro/Nm3 H2 produced	0,104	0,104	0,104	0,104	0,104	0,104
Net price hydrogen used by CHP (excl h2 grid contribution) Euro/Nm3 H2	0,37	0,34	0,31	0,27	0,24	0,21

Reformer cost, Euro/NM3 H2	7000	7000	7000	7000	7000	7000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	400	350	300	250	200	150
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0,27	0,24	0,20	0,17	0,14	0,10
Reformer hardware cost, Euro/Nm3 H2 produced	0,091	0,091	0,091	0,091	0,091	0,091
Net price hydrogen used by CHP (excl h2 grid contribution) Euro/Nm3 H2	0,36	0,33	0,29	0,26	0,23	0,19

Reformer cost, Euro/NM3 H2	6000	6000	6000	6000	6000	6000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	400	350	300	250	200	150
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0,27	0,24	0,20	0,17	0,14	0,10
Reformer hardware cost, Euro/Nm3 H2 produced	0,078	0,078	0,078	0,078	0,078	0,078
Net price hydrogen used by CHP (excl h2 grid contribution) Euro/Nm3 H2	0,35	0,31	0,28	0,25	0,21	0,18

Reformer cost, Euro/NM3 H2	5000	5000	5000	5000	5000	5000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	400	350	300	250	200	150
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0,27	0,24	0,20	0,17	0,14	0,10
Reformer hardware cost, Euro/Nm3 H2 produced	0,065	0,065	0,065	0,065	0,065	0,065
Net price hydrogen used by CHP (excl h2 grid contribution) Euro/Nm3 H2	0,33	0,30	0,27	0,23	0,20	0,17

Reformer cost, Euro/NM3 H2	4000	4000	4000	4000	4000	4000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	400	350	300	250	200	150
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0,27	0,24	0,20	0,17	0,14	0,10
Reformer hardware cost, Euro/Nm3 H2 produced	0,052	0,052	0,052	0,052	0,052	0,052
Net price hydrogen used by CHP (excl h2 grid contribution) Euro/Nm3 H2	0,32	0,29	0,25	0,22	0,19	0,15



Effect of methanolprice Vs effect of reformer cost

Reformer	7000	Euro/Nm3		
Methanol Price	300	Euro/Ton	0,29	Euro/Nm3 H2
Methanol Price	150	Euro/Ton	0,19	Euro/Nm3 H2
Price reduction	50%		34%	

Methanol Price	250	Euro/Ton		
Reformer	8000	Euro/Nm3	0,24	Euro/Nm3 H2
Reformer	4000	Euro/Nm3	0,22	Euro/Nm3 H2
Price reduction	50%		8%	

RES-FC Market

Control strategy
The FC is controlled by the heat demand because the hydrogen costs more than the produced electricity can be sold for.

If the heat demand is larger than the max possible production from the CHP, then the CHP is operated at its max yield,
and the rest of the heat demand is covered by import of electricity.
If the heat demand is smaller than the max heat yield from the CHP then the CHP is operated at a yield similar to the heat demand.
The size of the CHP is chosen to give balance between buying and selling of electricity,
in order to obtain the same price by buying and selling,

Size of one house:	100 m2			Average
		kWh/m2 year	kWh/year	kWh/day
Room heating and ventilation kWh/m2 year		15	1500	4,1
Domestic hot water kWh/m2 year (4 persons, 30 litre, delta t: 40 degree)		35	3500	9,6
Total Heat consumption kWh/year		50	5000	13,7
Electricity consumption kWh/m2		18	1800	4,9
Total		68	6800	18,6

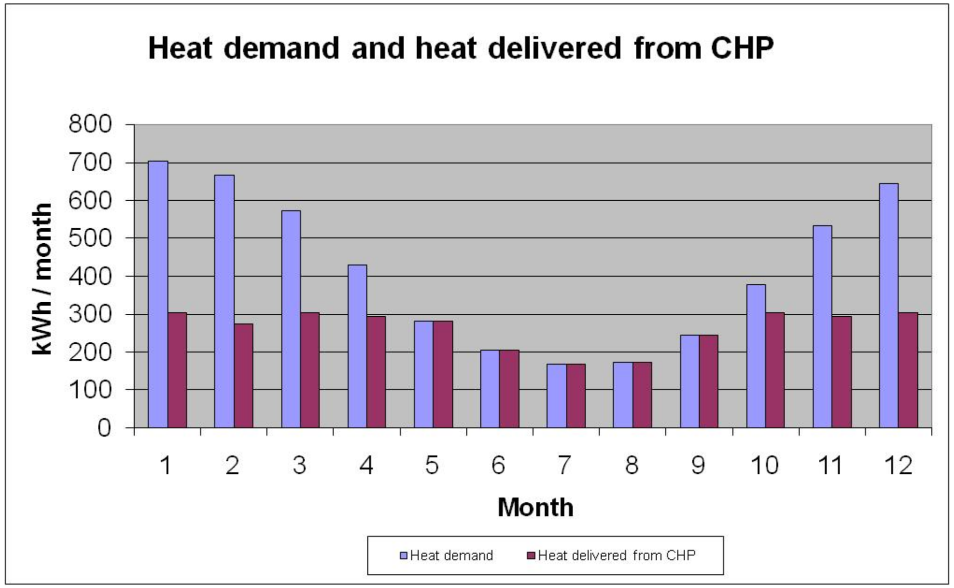
In a passive house the heating requirement is max 15 kWh/m2/year.
The electricity consumption is recommended to be below 18kWh/m2/year
That this is possible can be seen in the uploaded document: “Electric consumption in the household”.
The hot water consumption is calculadet to be 3500 kWh per house per year (4 persons including losses in pipes and storage tank).

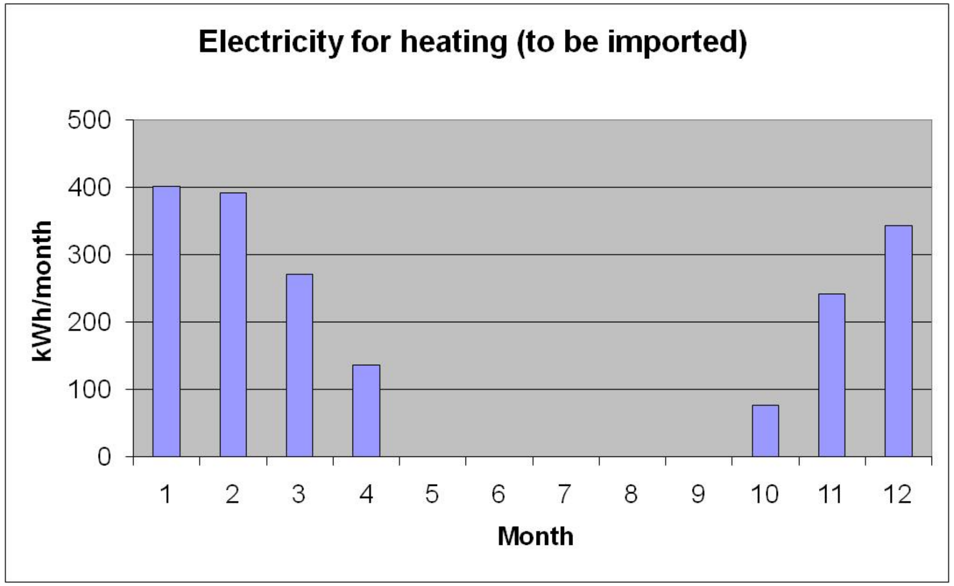
Input

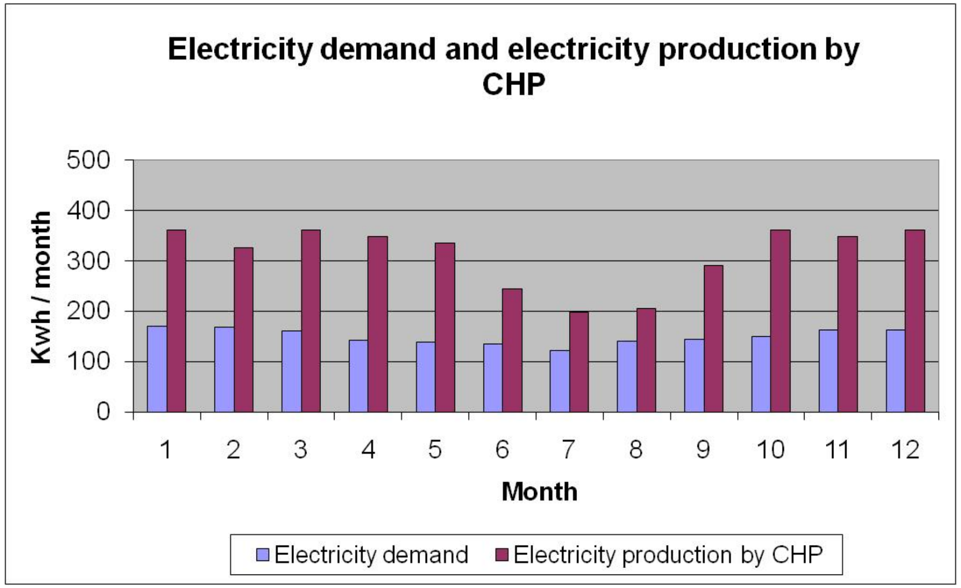
Electricity demand kWh/year	1800	
Heat demand kWh/year	5000	
Fuel-cell capacity kW-el	0.5	
Fuel-cell capacity kW-th	0.42	
Fuel cell efficiency kWh-el/Nm3	1.44	Actual FC system values are used
Fuel cell efficiency kWh-th/Nm3	1.22	
CHP energy efficiency	0.76	Based on HHV

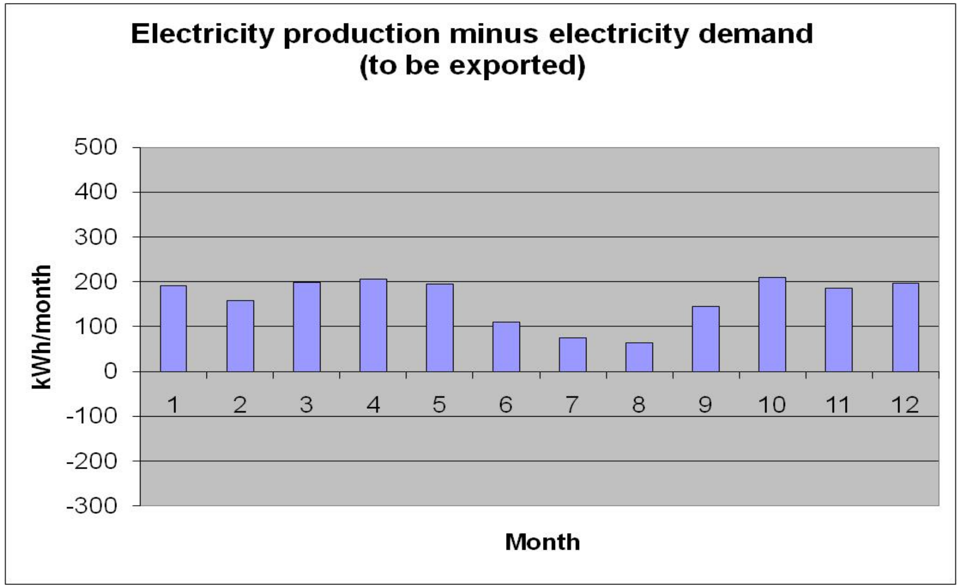
Output

Month	Hours	Max operation hours	Distribution Electricity	Heating	Demand Electricity kWh	Demand Heating kWh	Potential production Electricity kWh	Heating kWh	Production Heating kWh	Electricity kWh
January	744	720.75	0.09	0.14	169	704	360	303	303	360
February	672	651	0.09	0.13	168	666	326	273	273	326
March	744	720.75	0.09	0.11	161	574	360	303	303	360
April	720	697.5	0.08	0.09	142	429	349	293	293	349
May	744	720.75	0.08	0.06	139	281	360	303	281	335
June	720	697.5	0.07	0.04	135	205	349	293	205	244
July	744	720.75	0.07	0.03	123	167	360	303	167	199
August	744	720.75	0.08	0.03	141	173	360	303	173	206
September	720	697.5	0.08	0.05	145	244	349	293	244	290
October	744	720.75	0.08	0.08	151	379	360	303	303	360
November	720	697.5	0.09	0.11	163	534	349	293	293	349
December	744	720.75	0.09	0.13	163	645	360	303	303	360
sum	8760	8486.25	1	1	1800	5000	4243.125	3564.225	3140	3738


Heat demand and heat delivered from CHP


Electricity for heating (to be imported)


Electricity demand and electricity production by CHP


Electricity production minus electricity demand (to be exported)

Sizing and cost of methanol reformer

Daily electricity production max. kWh	12					
Fuel cell electrical efficiency kWh/Nm3	1.44					
Daily average hydrogen consumtion max, Nm3	8.1		Reformer and FC operates at same time, no h2 storage			
Number of hours FC is shutdodown in order to balance import/export: hr/day	0.8					
Size of FC, Nm3 H2/hr	0.69		= FC size	16.5956284	497.868852	Nm3 H2 / month
Number of houses at the estate	200					
Size of reformer Nm3/h	130					
yearly H2 production from reformer	1033828					
Reformer usage compared to 100% load, yearly avarage	90.5%					
Reformer cost, Euro/NM3 H2	6666	6666	6666	6666	8000	4000
Reformer Lifetime, years	10	10	10	10	10	10
Methanol Feedstock price, Euro/ton	110	110	310	310	200	110
Reformer operating cost, Euro/ Nm3 H2 (excl hardware depriciation)	0.08	0.08	0.21	0.21	0.14	0.08
Reformer hardware cost, Euro/Nm3 H2 produced	0.084	0.084	0.084	0.084	0.101	0.050
Net price hydrogen used by CHP (excl h2 grid contribution) Euro/Nm3 H2	0.16	0.16	0.29	0.29	0.24	0.13

Heat demand per day max. kWh	23	
Domestic hot water per day kWh	10	
Heat storage kWh	32	
Delta temperature 95- 45	50	
Heat storage m3 per house		
Yearly hydrogen consumption Nm3 per house	5169	0.
Yearly electricity consumption by electrolyser kWh per house		

Net price of hydrogen used by CHP Euro/ Nm3		0.16	0.16	0.29	0.29	0.24	0.13
Grid payment per kWh		0	0				
Grid payment per Nm3		0	0	0	0	0	0
PSO per kWh		0	0				
PSO per Nm3		0	0	0	0	0	0
CO2 per Kwh heavy process		0	0				
CO2 per Nm3		0	0	0	0	0	0
Electgricity tax per kWh		0	0				
Electricity tax per Nm3		0	0	0	0	0	0
Sum of tax ex. VAT		0	0	0	0	0	0
VAT %	25	0.04	0.04	0.07	0.07	0.06	0.03
Hydrogen price incl. tax per Nm3, Euro		0.20	0.20	0.37	0.37	0.30	0.16
Costs of hydrogen per house per year ex. depreciation Euro		0	0	0	0	0	0
Price of CHP Euro	200 systems in 2009. Price multiplied by 0,8 for 0,5 kW size	16,000	16,000	16,000	16,000	16,000	16,000
Lifetime of CHP year		10	5	10	5	10	10
Depreciation of CHP Euro/Nm3 hydrogen		0.31	0.62	0.31	0.62	0.31	0.31
[redacted]							
Costs of hydrogen incl. depreciation Euro/Nm3 H2		0.51	0.82	0.68	0.99	0.61	0.47
Costs of hydrogen per year incl. depreciation Euro		2638	4238	3495	5095	3132	2420
Consumer price of electricity incl. tax, Euro/kWh		0.27	0.27	0.27	0.27	0.27	0.27
Consumer price of heat incl. tax, Euro/kWh		0.13	0.13	0.13	0.13	0.13	0.13
Value of electricity production from CHP Euro		988	988	988	988	988	988
Value of heat production from CHP Euro		408	408	408	408	408	408
Value of CHP production per year		1,396	1,396	1,396	1,396	1,396	1,396
Value of CHP production minus cost of hydrogen, Euro per year		-1,241	-2,841	-2,098	-3,698	-1,736	-1,024
Heatproduction from CHP kWh		3140	3140	3140	3140	3140	3140
Electricity production - net export kWh		3660	3660	3660	3660	3660	3660

APPENDIX 3

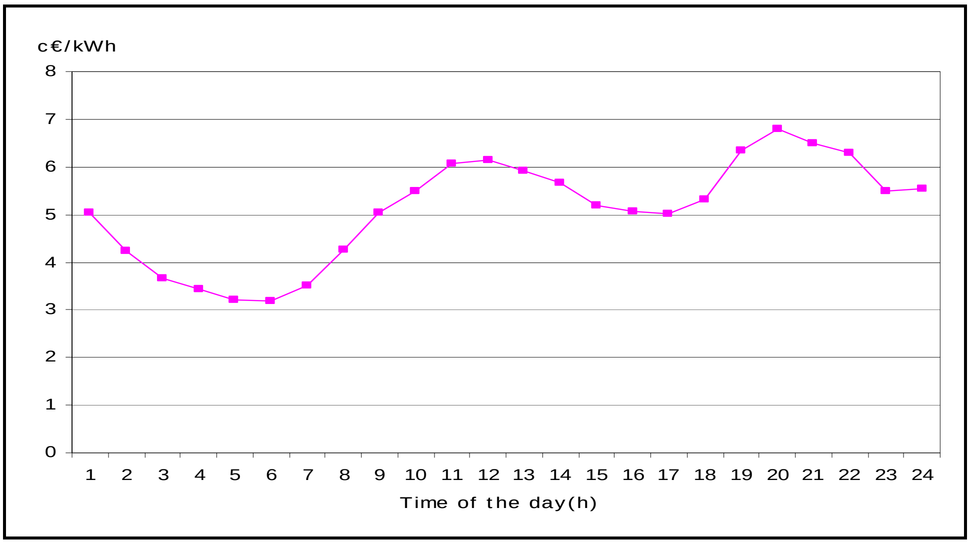


Figure A- 1. Mean price January 2007. Source:REE

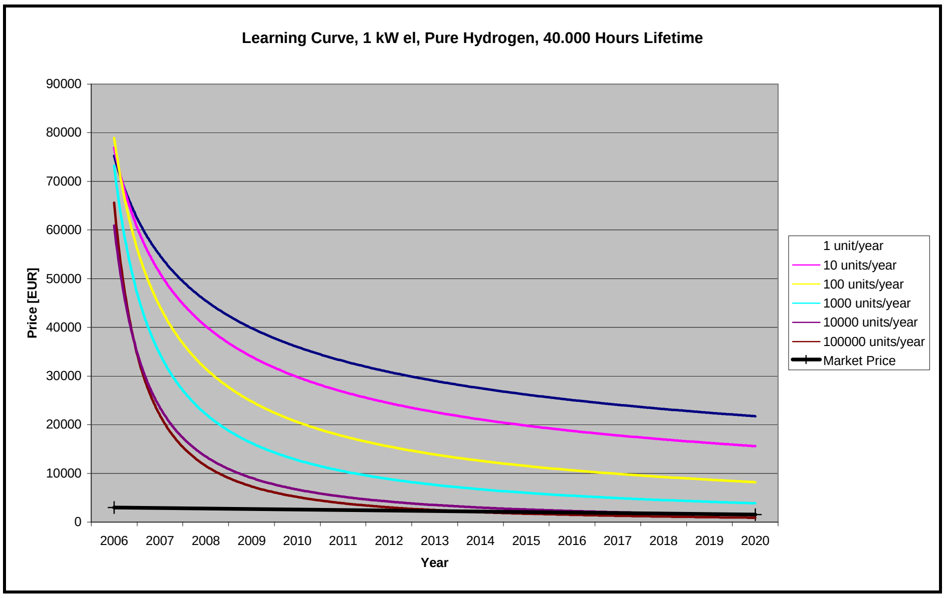


Figure A- 2. Learning curve, 1kWel, pure hydrogen, 40,000 hours lifetime

	Electrical efficiency	Total efficiency	Heating value (HHV)	Heating value (HHV)	Electrical Fuel Efficiency	Thermal Fuel Efficiency	Electric Capacity	Heating capacity
	[% HHV]	[% HHV]	MJ/l	kWh/Nm3	kWh/Nm3	kWh/Nm3	kW	kW
H2	41	76	0,013	3,50	1,44	1,22	0,50	0,42
NG	33	76	0,040	11,00	3,63	4,73	0,50	0,65
				kWh/l	kWh/l	kWh/l		
Metanol	35	76	17,2	4,78	1,69	1,94	0,5	0,58

Figure A- 3.values to calculate the overall energy efficiency based on a 0.5 kWe system

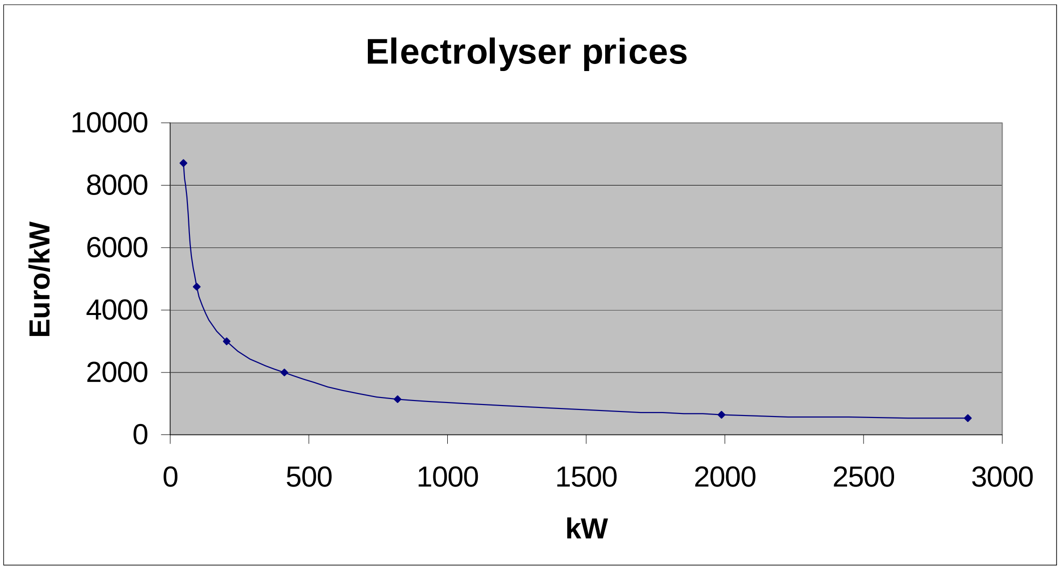


Figure A- 4.Electrolyser prices according to power

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Per Balslev, DANFOSS
Jesper Themsen, Dantherm.
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