Ten regional RES-FCHS market development plans

report on the 10 market development plans of RES-FCHS

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Ten regional RES-FCHS market development plans: Report on the 10 market development plans of RES-FCHS

RES FC Market Work package 3 - Deliverable 3.1

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WP3: 10 regional RES-FCHS market development plans

The objective of work package 3 is in accordance with the grant agreement page 17 to make market development plans (MDPs) for the 10 potential RES-FCHS markets for the three RES FCHS solutions in the five involved countries.

The work package is split up into three deliverables of which this report contains the first

Deliverable 3.1: Report on the 10 market development plans of RES-FCHS

The market development plans are made by the involved partners according to the following distribution of responsibility which also indicates the technology / geographic area combinations that are investigated.

Technology and geographic area	Responsible institution
• Biogas – possibly mixed with natural gas	
o Jutland, Denmark	AAU Esbjerg
o Baden-Württemberg, Germany	IBBK
• Ethanol/methanol from bio-resources	
o Jutland, Denmark	DONG Energy
o Baden-Württemberg, Germany	KIBZ
o Reykjavik, Iceland	University of Iceland
• Low cost excess wind electricity/hydrogen	
o Jutland, Denmark	HIRC
o Schleswig-Holstein, Germany	KIBZ
o North Friesland, The Netherlands	ECN
o Navarra & the Basque Country, Spain	CENER
o Coimbra, Portugal	ISR-UC

In addition, six partners have the task of providing ad hoc technology support for the partners elaborating the ten market development plans. These are:

• Technology support Wind	CENER
• Technology support Biogas	IBBK
• Technology support Methanol	DONG Energy
• Technology support FC Systems	DT
• Technology support Fuel Cells	IRD
• Technology support Electrolysers	BIC

WP3

AALBORG UNIVERSITET ESBJERG

Regional Market Development Plans

Biogas in Jutland, Denmark

Jens Bo Holm-Nielsen, Piotr Oleskowicz-Popiel & Michael Madsen

Contents

1 Introduction to the biogas resources in Jutland

The Danish peninsula Jutland has a long history of activities related to agriculture. Jutland is characterised by a high livestock density and a high level of farming activities including among other things intensive cultivation of crops. Hence, biomass and biomass residues are transported regionally in various forms.

Agricultural residues (manure from livestock production, residues from crop cultivation and forestry, and wastes from abattoirs and food processing industries) are to a large extent treated at centralised biogas plants through the anaerobic digestion process (AD). The main products of the AD process are a certified organic fertiliser (the digestate) and renewable energy in the form of biogas (mixture of 65 vol-% methane and 35 vol-% carbon dioxide). The largest benefits associated with biogas plants include better utilisation of the nutrients in the digested manure, redistribution of nutrients on farmland, and reduction of greenhouse gas emissions (mainly methane and nitrous oxides). At the same time, the majority of the obnoxious odours are removed improving the public perception of agricultural related activities; manure handling and biogas production in particular.

Biogas plants use approximately 1/3 of the generated biogas to cover the need for on-site process energy, while the remaining 2/3 is sent via pipeline to a nearby combined heat and power plant utilising the biogas in special gas engines adapted to the biogas fuel. At present, an estimated 1,5 million tonnes of manure and approximately 350 000 tonnes of industrial organic waste is annually treated at all biogas plants in Denmark. The centralised biogas plants suffer from the fact that manure has a low biogas potential. High-quality organic waste rich in fat and oil has to be added in order to make the plants economically viable. A recent study concluded that the biogas plants can reduce their dependency on organic wastes from the industry and secure their economic bottom lines, if they adapt novel technologies to pre-treat manure and by this optimise the biogas yield from manure. In time, biogas plants can be operated on solely manure and become economically viable. Between 5 % and 10 % of the manure potential is utilised for biogas production at the moment. It has been estimated that the biogas sector can produce up to 26 PJ per year from the national manure resources at hand today. Hence, a large biogas potential is readily available.

[Nielsen et. al. 2002 and Christensen et. al. 2007]

Besides biogas produced from AD, modern gasifiers are also relevant to consider. The biogas produced from gasification of for instance woody biomass generates a much cleaner gas compared to biogas arising from AD. Biogas generated by gasification in a Batelle gasifier is likely to be used directly in a Solid Oxide Fuel Cell (SOFC) system without the need for further external fuel processing. [Peppley 2006]

Use of biogas for decentralised combined heat and power production in small-scale fuel cell applications can require significant investments, both for distribution grids for biogas from plants to the end-users, but also with respect to biogas upgrading facilities. The following sections address some of the main barriers in connection with utilisation of biogas in fuel cell installations in Jutland.

2 Utilisation of biogas in fuel cell systems – main conclusions from literature review

Peppley (2006) stated that several authors have already published theoretical and practical feasibility studies and preliminary results from experiments, where biogas has been utilised successfully in fuel cell systems. The systems are covering many different fuel cell technologies and output power ranges. Hence, the studies have relevance for many different application scenarios.

These studies have overcome many of the technical barriers and practical problems related to utilisation of biogas in fuel cell systems. The studies have assessed, among other things, impurities in the biogas and fluctuations in the fuel quality. The main conclusions from these studies were that biogas most likely needs to be cleaned for certain pollutants, before being distributed to the fuel cell systems. Especially hydrogen sulphide possesses a risk, since this compound can lead to deactivation of most fuel cell systems.

The fuel cell systems were generally able to operate on biogas with varying methane content indicating that upgrading the biogas to natural gas quality is not always necessary. This of course has to be analysed in detail in a local context. Is there a local market for raw biogas, or is it necessary to upgrade it and gain access to a larger regional or national market via the established natural gas grid?

Variation in the composition of the produced biogas is inevitable due to nature of the feeding profile. The biogas plants usually do not get a uniform organic waste from their suppliers, but the composition of the waste may vary from truck load to truck load. This affects the biogas process itself leading to fluctuation in the biogas composition (methane, carbon dioxide, and hydrogen sulphide). [Staniforth and Kendall 1998]

Solid Oxide Fuel Cells (SOFC) have been emphasised as especially suitable for handling biofuels with varying quality. [Sasaki et. al. 2004]

2.1 Distribution of biogas

The established combined heat and power generation systems based on biogas in Jutland utilise the biogas directly in gas engines without the need for upgrading. The amount of hydrogen sulphide in the biogas is reduced by biological or chemical cleaning, and the biogas is dried before injected into pipelines. Besides that no treatment is carried out.

Injecting upgraded biogas into the nation-wide natural gas grid seems like a favourable idea. However, natural gas is often supplemented with odorants for safety reasons. Many of these odorants contain sulphur and thus the gas probably needs to be cleaned at the destination, before being used in fuel cell systems. Establishment of a large integrated network is therefore a complicated task. [Sasaki et. al. 2004]

Common biogas quality parameters for gas engines are given in table 1.

Table 1. Common fuel requirements for gas engines [Jensen 2000]

Parameter	Unit	Interval
Energy content	MJ / m^3	13-21
Variation in energy content	MJ / m^3	0-2
Maximum temperature feed	ºC	40-60
Minimum delivery pressure	mbar	25-80
Biogas humidity	%	< 70-80
Hydrogen sulphide	mg/m^3	< 1000-2000
Sum of fluorine and chloride	mg/m^3	< 60-80

2.2 Upgrading biogas to fuel cell quality

Staniforth & Ormerod (2002) showed that a SOFC system could be operated on biogas with varying methane concentration and varying flow rates. Maximum power output of the system occurred at a methane concentration of 45 %. However, the content of hydrogen sulphide in biogas has to reduced or eliminated, since sulphur causes deactivation of the anode. Biogas can be utilised in SOFC systems directly without adding for instance air or steam.

Naumann and Myrén (1995) reported experimental results from a development programme that investigated the feasibility of small fuel cell based power plants for implementation in developing countries. They observed that using biogas resulted in a larger production of hydrogen in the fuel cells compared to using natural gas. Carbon dioxide seemed to have a positive influence on the utilisation of the methane. The efficiency of the phosphoric acid fuel cell (PAFC) system run on biogas was comparable to similar systems operated on natural gas.

The question, whether the produced biogas has to be upgraded to a natural gas quality thus becomes a local decision.

Upgrading of biogas can be done in several ways; the most common techniques are listed below [Persson, 2003 and AD-NETT, 2000]

1. Pressure Swing Adsorption (PSA) – within this method carbon dioxide, nitrogen, and oxygen are removed by adsorption on zeolites or activated carbon. The upgrading of biogas is carried out at increased pressure, and the material is regenerated by decreasing the pressure. In this process hydrogen sulphide has to be removed before, to avoid destroying the adsorption material. The PSA technique gives up to 98% efficiency.

2. Absorption in water – carbon dioxide, hydrogen sulphide and ammonia physically dissolve in water under pressure. Water washing is one of the most popular techniques in removing CO_2 from biogas.

3. Absorption in polyglycol – this method is very similar to water wash. Selexol and Genesorb are to trade marks for chemicals, which are also used as common names for this process. The solubility of carbon dioxide and ammonium is higher in Selexol than in water.

4. Absorption with chemical reaction – the absorption material reacts chemically with components of biogas. Ethyl amine is one of the examples of chemical applied in this method. This process is highly selective for carbon dioxide (sometimes for H_2S as well), therefore no methane losses are observed. All absorption techniques have high efficiency up to 95%.

5. Membrane separation – this treatment can be divided in wet and dry separation. Dry process is based on difference in permeability difference between methane and carbon dioxide. In the wet technique the fluid on the other side of the membrane selectively absorb specific compounds. The efficiency of the membrane separation technique differs from 73% to 83%.

6. Cryogenic process – CO_2 is condensed during compressing and chilling biogas. The method is based on different conditions in condensing CO_2 and methane. CO_2 compared to CH_4 requires lower pressure and higher temperature.

For security reasons cleaned and upgraded biogas has to be odorized before being used as a vehicle fuel or injected in the natural gas grid. The most common compounds are tetrahydrotiophen (THT) and mercaptans [Persson, 2003]. If the gas is to be added to the natural gas piping system it has to be cooled down and compressed. Table 2 summarises different upgrading techniques.

Table 2. Properties for different upgrading techniques [Persson, 2003]

Property	PSA	Water wash with regeneration	Water wash no regeneration	Selexol	Absorption with chemical reaction
Main operation interrupt	Valves	Plugging of packings	Plugging of packings	Water in the Selexol	-
Energy need electricity/m^3 cleaned gas acc. to plant	0.5-0.6 kWh	0.3 kWh	0.4-0.6 kWh	0.4 kWh	-
Energy need electricity/m^3 cleaned gas acc. to supplier	0.3-1.0 kWh	0.45-0.9 kWh	0.45-0.9 kWh	-	0.15 kWh
Energy need heat	None	None	None	None	High (regeneration)
Water consumption	Low	Medium (tap water)	High (Cleaned sewage water)	Low	Low
Chemical consumption	Low	Low	Low	High	High
Gas quality, methane	High	High	High	Medium (low methane level when water in S.)	High
Gas quality, security against hydrogen sulphide in gas	High	Low	Low	Medium	Medium – High (depending on chemical)
Gas quality, security against humidity in gas	Medium	Low	Low	Medium	Low – High (depending on chemical)
Methane losses	Medium – High	Medium – High	Medium – High	Medium – High	Low
Possibility to measure methane losses	Yes	Partly	No	Yes	Yes

Figure 1: Upgrading costs per m^3 SNG for full-scale upgrading plants operating in Europe and the USA [Jensen, 2000].

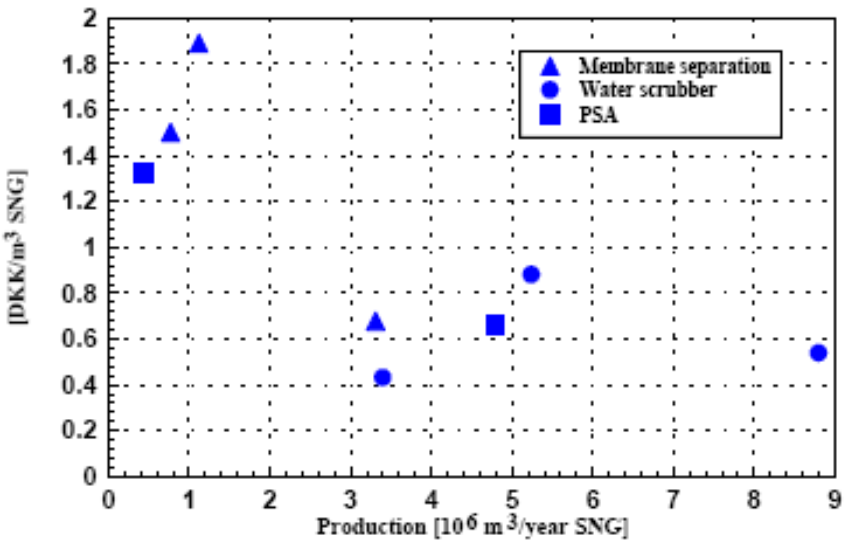

Figure 1. Upgrading costs per m^{3}SNG in function of different upgrading technology and the plant capacity (Jensen, 2000).

It can be easy to notice that water scrubber is the most economical in big scale up 90 Mm^3/year. In production scale around 10 Mm^3/year the upgrading costs can be 2-4 times higher.

3 Specific steps needed to develop the market

Definitely, support form government in form of introducing feed-in-tariffs, tax reduction, or carrying out research and demonstration projects would significantly improve the market for renewable energy. It would make it easier for the private sector to invest in bioenergy.

The VAT rates for bioenergy are different for each country. To increase competitiveness of bioenergy VAT rates should be decreased for all bioenergy related products and services. This should include all biofuels (gaseous, liquids, and solids), all conversion technologies and its final products (heat and electricity).

Good examples are Germany and Sweden.

In the first one the government is supporting farmers, who switch into energy crop production. Whereas, in Sweden biofuels are applied in public transport, moreover i.e. there is tax reduction for cars which can run on biofuels.

European Union has already initiated switch into bioenergy (Josart, 2006):

- The White Paper (COM(1997)599) on renewable sources of energy which aims at doubling RES from 1995 to 2010, from 6 to 12% of the EU's gross inland energy consumption.
- Directive (2001/77)) for the promotion of electricity from RES that sets out an objective of 22,1% RES-E for 2010 and individual targets for member states
- Directive (2003/30) for the promotion of liquid biofuels that proposes a target of 5,75% for all countries by 2010,
- Communication (COM(2004) 366) evaluates the state of development and concludes that targets will not be met by using business-as-usual policies in the Member States.

(Josart, 2006) point out what should be done in order to develop bioenergy market in Europe. He underlines, that is has to apply to the whole chain of bioenergy: from raw materials to equipment and services, to sales of final products. His statements are (Josart, 2006):

- Establish fair competition between domestic bioenergy as against the oil and natural gas industries and imported biofuels;
- Develop infrastructure to produce/collect transport biomass, and supply energy to clients in a way that is as convenient as fossil fuels. Pellets are part of the success stories in Austria or Sweden for example;
- Removal of administrative barriers to bioenergy projects (speed up the delivery of permits, etc.);
- Guarantee fair grid access for bioelectricity and biogas;
- Set up more demonstration projects to widen the range of reference plants and spread experience in new energy chains. These projects are a very good basis for dissemination activities;
- Remove barriers such as the unreasonable treatment of biomass as waste, inflated fire safety precautions and excessive delays in obtaining permits for bioenergy projects;
- Harmonise trade regulations at EU level;
- Speed up the implementation of Directive 2003/30 on liquid biofuels. Mandatory targets should be considered;
- Give incentives on the demand side for bioenergy (e.g. no parking fees for biofuel fuelled cars in cities);
- Promote the renewal of public and private/agricultural transport fleets that are biofuel compatible.

Besides that very important is education of society about alternative of bioenergy as well as increase public awareness of present fossils-based energy system. Therefore bioenergy should be promoted, so the society will understand it as reliable, economic, and environment friendly.

3.2 Regional case examples

Another contribution in WP3 titled "*Low cost excess wind electricity/hydrogen in Denmark*" has described various areas, where fuel cell systems can be implemented. The same scenarios could be based on fuel derived from biogas in stead of wind power. These descriptions are not reproduced in this contribution. Out of the three cases described (Nakskov, Herning, and Sønderborg), biogas is only to be applied in the Sønderborg-case. A biogas plant is in the planning phase in Nakskov. It is therefore possible that in time it will also be possible to feed fuel cells with biogas in Nakskov in preliminary tests.

3.3 Stakeholder analysis

Stakeholders deciding on the framework conditions have been described in the WP3 contribution "*Low cost excess wind electricity/hydrogen in Denmark*" and will not be repeated here.

Technology carriers include stakeholders capable of delivering technology for production and distribution of biogas, companies capable of providing the necessary upgrading and gas cleaning technology, service providers, and relevant authorities.

Injection of upgraded biogas into the nationwide natural gas grid is a necessary pre-requisite in order to facilitate a swift development of the biogas sector. The major Danish natural gas companies in Jutland (Naturgas MidtNord and DONG Energy) would have a keen interest in distributing and upgrading biogas in order to meet fuel cell specifications. Quality and safety control could be administered by Dansk Gasteknisk Center (DGC) and the authority Sikkerhedsstyrelsen.

Manufacturers of biogas plants (e.g. Xergi A/S, Lundsby Bioenergi A/S, Schmack Biogas AG etc.) and their subcontractors (e.g. GE Jenbacher A/S, ScanAirClean A/S etc.) all have the interest, power, organizational structure, technology access, and are able to generate the knowledge needed for quickly establishing a wide biogas production and distribution network. Meanwhile, the political framework (including guaranteed minimum price index-linked feed-in tariffs for biogas) has to be in place before any significant action can be expected from the industry.

Table 3: Overview of the actors in the natural gas and biogas sector

	Natural gas companies: Nat Gas Midt Nord DONG Energy	Manufacturers of biogas plants: Xergi Lundsby Bioenergi Schmack Biogas	Subcontractors: GE Jenbacher A/S ScanAirClean A/S
Interest	Yes	Yes	Yes
Power	Yes	Yes	Yes
Organisation	Yes	Yes	Yes
Information	Yes	Yes	Yes
Access	Yes	Yes	Yes
Knowledge	Yes	Yes	Yes

3.3 Ongoing demonstration projects

Naturgas MidtNord is planning and conducting a full-scale biogas upgrading test at Thorsø biogas plant and DONG Energy is involved in similar upgrading tests at Aarhus University, Foulum Research Centre. The involvement of these two major players in the distribution chain at present time indicates that they have a vested interest in developing and assimilating technologies needed for large-scale biogas cleaning and distribution.

4 Future perspectives

A lot of research efforts are being put into development of technologies that can utilise waste streams in an intelligent way an, among other things, produce renewable energy.

One interesting aspect of advanced waste treatment is monoculture fermentation of the organic fraction of municipal waste (household waste) yielding high-quality biohydrogen that can be utilised directly in fuel cells. Experimental data from laboratory tests are promising and pilot-scale testing is ongoing. [Gambacorta 2007]

5 Conclusions

Several scientific studies, where biogas is used in fuel cell systems, have been reported over the past two decades. The systems are diverse and span over many technologies and many different output power ranges. Hence, they can meet the energy demands for many different scenarios.

Biogas produced from anaerobic digestion contains sulphuric compounds that have to be removed prior to utilisation in fuel cell systems. Otherwise the fuel cells will be seriously affected and in time deactivate completely.

Concerning distribution of the biogas to a larger market, there are several alternatives that can be considered. Upgrading biogas to natural gas quality by removing carbon dioxide is costly and does not necessarily beneficiary. Presence of carbon dioxide in biogas has been reported to have a positive effect on the fuel cell performance indicating that utilisation of biogas directly is a viable option. The standardisation thus makes it difficult to access a larger, regional market.

However, biogas can be produced via other technologies than just anaerobic digestion. Gasification of for instance woody biogas produces a much cleaner biogas that requires little or no cleaning with respect the sulphur. Introducing a variety of biological feedstocks would probably also create a much more stable market with limited fluctuations.

In the future, clean biohydrogen can be produced directly from organic waste using microbial monocultures.

A detailed mapping of the bioenergy resources is necessary in each local community in order to conclude, which technologies and distribution systems that are feasible to implement.

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7 Similar biogas fuel cell projects of interests

BIOSOFC: Design and demonstration of 4 CHP Plants using two 5 kW Solid Oxide Fuel Cells (SOFC) working with landfill gas and biogas from anaerobic digestion.
Website: http://www.biosofc.info/project.php

Cowpower: Fuel cell feasibility for energy conversion on the dairy farm
Website: http://www.cowpower.cornell.edu

WP 3

Regional Market Development Plans

Ethanol/methanol from bio–resources / Baden – Württemberg, Germany
Wind power / Schleswig–Holstein, Germany

Bernhard Schaible

Contents

1 Introduction

The focus of this report is on market developments plans for

- Different technologies and
- On geographic areas.

To come to substantiate conclusions, a number of important stakeholders in the sectors of renewables, fuel cells, and corresponding technologies were interviewed. The Hanover fair offered a good opportunity to interview many of these stakeholders.
Attachment 1 lists the institutions, which were or will be interviewed.

KIBZ is supposed to study the availability of *ethanol/methanol from bio-resources* and of *low cost excess wind electricity* to produce hydrogen through electrolysis.

The geographic areas to be looked upon are Baden – Württemberg and Schleswig – Holstein in Germany.

The study will thus encompass market development plans for the following combinations of technologies and geographic areas

Ethanol/methanol from bio-resources/Baden–Württemberg
Baden–Württemberg´s wind energy capacity is the lowest among the bigger German states. It therefore makes sense to look at ethanol/methanol from bio-resources as a renewable alternative for this state.

Wind power/Schleswig–Holstein
In Germany most wind energy is obtained in the coastal regions of the North Sea as well as the Baltic Sea. The three German states Mecklenburg-Vorpommern, Niedersachsen, and Schleswig-Holstein with coastlines contribute about 50% of the installed wind energy.

In Mecklenburg-Vorpommern, located at the Baltic Sea, in an average year more than 32 % of the state's electricity demand can be covered through wind energy. Niedersachsen, bordering the North Sea, ranks among the German states with the biggest capacity in wind energy. Schleswig-Holstein 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). So it should be quite promising to have a closer look at the combination of wind energy and the geographical area of Schleswig–Holstein, even though the state ranks only 5th in Germany in terms of producing wind power (see http://www.wind-energie.de/de/statistiken/bundeslaender/).

2 Ethanol/methanol from bio – resources/Baden–Württemberg, Germany

Even though Baden–Württemberg is highly industrialized, it is one of the German states with the highest density of biogas producing plants. One could assume that heavy industrialization in a densely populated country means small size farms, which are contraproductive to biogas plants. Even though there are fewer big size farms in the south west of Germany they seem to be more open to biogas plants.
(see http://www.uni-hohenheim.de/i3v/00217110/02132041.htm).

Biogas, a "downgraded methane" with about 60% of CH_4 could be a suitable precursor for methanol. Even though **ZSW** (Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg = Center for Solar Energy- and Hydrogen-Research Baden-Württemberg)

has shown in a pilot plant that the obtained biogas from a fermenter can be processed to methanol, this is done nowhere in Baden–Württemberg. This also holds true for Germany. Methanol so far is produced from natural gas. The only methanol with an "ecological touch" is produced from organic waste in Eastern Germany at the "Schwarze Pumpe" plant.
Therefore the *emphasis* will be *on ethanol from bio–resources*.

In Germany bioethanol is produced by **Südzucker Bioethanol** GmbH (s. attached interview from August 2006, which was verified by Mr. Hinz/Südzucker Bioethanol GmbH during a visit to KIBZ at the beginning of 2007). The company is one of Europe's leading bioethanol manufacturers. It was set up in 2003 to explore new sources of energy from renewable raw materials.

Main production site of this young company is Zeitz in Saxony-Anhalt. The plant there was brought on stream in 2005. It is one of the largest of its kind in Europe, with an annual bioethanol capacity of 260,000 m³. The bioethanol is produced by fermentation of wheat or sugar beets. Germany contributes 260 mio. liters to the current production of 330 mio. liters per year in Europe. Within 3 years the production shall be increased to 3 billion liters. In the future sugar cane may also be used in the fermentation process.

With its bioethanol production, Südzucker Bioethanol GmbH aims at the automotive sector. The German government made an admixture of 3 vol.% mandatory by January 1st, 2007, which will help the company to reach its goal.

So far the company hasn't looked into bioethanol for the residential market. But together with the Fraunhofer Institute ICT in Karlsruhe, Südzucker Bioethanol GmbH started research on a direct ethanol fuel cell[1)]. A single layer cell was exhibited at the Hanover fair in April, 2007!

A more recent update of Südzucker Bioethanol GmbH's statement so far hasn't been possible, because of difficulties to find a date for an interview. But it is on the agenda.

During the Hanover fair in April, 2007, it was possible to interview Mr. Lackmann, the CEO of the **Bundesverband Erneuerbare Energien e. V. (BEE)**, a non-profit association, which represents the interests of the "renewable energies industry". He made the following statements:

1. Biogas through fermentation or gasification should be used as such in CHP plants (e. g. MCFC or SOFC) or should be upgraded to natural gas quality (SNG), which could be fed into the grid (as soon as regulations are in effect). This SNG could be used for mobility or for fuel cells in households. It should not be processed to biomethanol.
2. Energy plants should only be used to make biogas. The synthesis of liquid fuels from plants doesn't make sense, since the "harvest" of biogas per acreage is about twice as high as for liquid fuels (e. g. bioethanol, btl,…)

This goes together well with an article in the well-known weekly "Die Zeit" from April. 19th, 2007, which recommends the use of biogas as such (where possible) or upgraded to SNG. Processing plants to bio liquids would cut yield in half.

dena (**Deutsche Energie - Agentur GmbH** = German Energy Agency), the German center of competence for energy efficiency favours efficient and at the same time ecologic ways of providing energy with the emphasis on renewable energies. dena prefers any carrier of re-

[1] Fuel oil amounts to 0,62 €/l (quantity: 20.000 l, free delivery), bio ethanol with about 64% of the heating value of oil is about 0,64 €/l, ex factory (same quantity)

newable energy suitable for fuel cells (e. g. upgraded biogas, and bioethanol – depending on the application).

Conclusion: Regional Market Development Plans for methanol/ethanol from bio–resources in Baden–Württemberg

- No *methanol* is or will be produced in the middle-term future from bio-resources in Baden–Württemberg or Germany. It is very difficult and by no means rewarding to produce methanol from bio-resources - worldwide. B-W is no exemption of this fact.
- *Ethanol* is produced by Südzucker Bioethanol GmbH on a technical scale in Zeitz in East Germany, but not in Baden–Württemberg. The company is the biggest producer of bioethanol in Germany.

Barriers:

- Südzucker Bioethanol GmbH, the producer of bio-ethanol, aims at the automotive sector, which competes with fuel cells for this renewable. Südzucker Bioethanol GmbH aims at the automotive sector, because they assume, they will get better prices in that sector. The company is not interested in the use of ethanol for residential fuel cells. Research just recently has started with direct ethanol fuel cells (defc). But this aims at the power supply of portables, where even higher prices can be charged than in the automotive sector (such as lap tops).

Solutions:

- Baden–Württemberg is one of the leaders in biogas production in Germany, however. In this state the first MCFC from MTU CFC Solutions GmbH, Munic with biogas feed went on stream in Leonberg near Stuttgart in October, 2006. Its electrical efficiency should average 47 % (output is 240 $kW_{el.}$) and the overall efficiency should exceed 90 %.

  Local utility companies are starting to upgrade biogas to natural gas quality to be able to feed it to the grid. This upgraded biogas (SNG) as a renewable energy source (for fuel cells etc.) could play a role in the future, if the grids are opened for SNG by law. This SNG could feed fuel cells at any place that is connected to the natural gas grid. And the energy efficiency of biogas per acreage is about twice as high as for liquid fuels such as bioethanol. So SNG could become an interesting feed for residential fuel cells.

3 Wind power/Schleswig–Holstein, Germany

EON is the major provider of power and gas for regional/local utility companies in Schleswig – Holstein. The company so far hasn't looked at the possibility to use surplus wind power to make hydrogen. This may become a topic, when the company will start operating off shore wind parks.
Because of that, KIBZ contacted other utility companies in neighbouring areas with access to wind power and associations, which are active in the segment of renewables.

EWE is a local energy provider (power, also from wind energy, and natural gas) situated in Oldenburg in northwestern Germany. As an operator of windmills the company also is testing an electrolyser in combination with a Mark 1B fuel cell from Ballard, considering different operational strategies to use surplus power, including the storage of hydrogen.
However, in the opinion of EWE, this hydrogen should feed fuel cells in mobile applications. But EWE doesn't rule out that surplus power might be used to produce hydrogen for residential fuel cells in the future.

Background: Surplus power from wind energy can even achieve a negative price at the European Energy Exchange (EEX), even though the tariff for wind on land is 0,0836 (decreasing to 0,0528), for wind harvested off shore it is 0,091 Euro/kWh (decreasing to 0,0619). (These wind tariffs are decreasing at an annual rate of 2%.)

Vattenfall is one of the largest power suppliers in Germany. Its activities centre on Hamburg and the eastern part of Germany. In the future Vattenfall thinks about offshore wind parks.

The statements from Vattenfall:

- Basically the power from these parks will be fed into the grid.
- Surplus power can be stored as hydrogen.
- As a rule, this hydrogen will be used to sustain mobility (as hydrogen in a projected filling station in Hamburg or after conversion into synthetic fuel).
- Smaller quantities of hydrogen can be fed into local hydrogen grids, to supply local city and housing development projects in areas with excess wind energy (e. g. Hafencity Hamburg) using PEM-fuel cells.

Quintessence: Especially for Vattenfall, surplus wind energy might be interesting as a mean to generate hydrogen, which (only) in individual cases can be used for fuel cells in residential areas.

The **Bundesverband Windenergie e. V.** is a non-profit association, which represents the interests of the “wind industry”. Unfortunately the association doesn’t seem to be interested in the topic of this project at all. The associations` sole task is lobbying for wind energy (better tariffs, priority for the feed of wind energy to the power grid…)

The **Bundesverband Erneuerbare Energien e. V. (BEE)** is a non-profit association, which represents the interests of the “renewable energies industry”. BEE has the point of view that the power grid should be developed further to prevent such things as surplus wind energy. By doing this, inefficient strategies could be avoided, like producing hydrogen from power, which in turn would be used to produce power through fuel cells.

Conclusion: Regional Market Development Plans for wind energy in Schleswig – Holstein

Barriers:

- All interviewed parties were reluctant to use surplus power to make hydrogen, which in turn could be used to feed residential fuel cells. This seems comprehensible, since it takes about 4 kWh to produce 1 m³ of hydrogen, which in turn can be converted to roughly 2 kWh of energy by a fuel cell system (power and heat).
- This applies for Schleswig–Holstein as well as for Germany.
- The interviewed parties think that hydrogen is too precious to be used for stationary applications. If surplus power can not be avoided, it should be used feed fuel cells in mobile applications.

Solutions:

- Only EWE, the Oldenburg utility company (Lower Saxony) can imagine that hydrogen from surplus wind energy could be used as an energy source for fuel cells in households in the future. This might be especially interesting, if the price tag for wind power becomes negative, as it has already happened, - and if the fee for the transport of the power in the grid doesn’t compensate this incentive.

4 Overall Regional Market Development Plans/Germany

The updated German national development plan (Nationaler Entwicklungsplan, Version 2.0 of February, 2007, pp. 12 - 16.) assumes 450 fuel cell units for households by 2010, 2.250 units by 2012, and 72.000 units p. a. by 2020 for Germany. *The energy output of these systems is between1 and 5 $kW_{el.}$ unlike the assumed range of 0.5 – 1 $kW_{el.}$ in our project.*

For 2020 the price target is 1.700 €/kW in addition to comparable costs of conventional systems (see figure 1). This should give fuel cells a fair chance. These figures were aggregated by a survey done with the producers of fc–heating installations and utility companies, which have closed ranks (www.initiative-brennstoffzelle.de).

The following German companies are members of this initiative:

- BAXI INNOTECH GmbH
- BBT Thermotechnik GmbH
- Deutsche Energie-Agentur GmbH (dena)
- E.ON Ruhrgas AG, Essen
- EnBW Energie Baden-Württemberg AG
- EWE AG Oldenburg
- Hexis AG
- MVV Energie, Mannheim
- RWE Fuel Cells
- Vaillant GmbH
- Viessmann Werke GmbH & Co KG
- VNG Verbundnetz Gas Aktiengesellschaft, Leipzig

Most of these companies (plus additional stakeholders) have been interviewed for the project (see attachments).Even though Baden–Württemberg is a center for stationary fuel cells besides North Rhine–Westphalia and Lower Saxony in Germany, these aggregated figures unfortunately don't show:

- Numbers for specific geographic areas
- Numbers for producers of the systems
- Numbers for the utility companies active in fuel cells
- A differentiation between SOFC- and PEM – systems
- Etc.

Barriers:

However, the updated German national development plan names the barriers, which have to be overcome.

For phase I (2007 – 2010) main barriers are:

- Low temp. PEMFC: Higher lifetime, less damageable by impurities, less sophisticated water management
- High temp. PEMFC: Higher lifetime, higher power density,
- SOFC: Higher lifetime (cycles), durability against redox environment
- Standardized BoP elements
- Better reformers (it is assumed that natural gas will be the energy carrier for the time being).
- Etc.

For phase II (2011 – 2015) main barriers are:

- Reduction of costs (for the elimination of impurities, for catalysts, for stacks)
- Reforming of biogas and fuel oil
- Higher power density and higher lifetime
- "Assembly line – production"

Solutions:
It is the target of the national development plan to solve these problems and achieve a validated technology by 2015.

5 Introduction to the actor analysis

The most important stakeholders for the RES-FC Market are

- The producers of fuel cell systems
- The users of these systems, so far in general utility companies
- Producers of energy carriers from sustainable sources, in this case bio-ethanol and biogas from renewables and hydrogen from wind energy

The producers of fuel cell systems and the utility companies have closed ranks in the Initiative Brennstoffzelle (Initiative Fuel Cell, www.initiative-brennstoffzelle.de) out of a common interest. The producers need the utility companies to do their field tests, while the utility companies want to learn more about the performance of the fuel cell systems.

To come to substantial conclusions, the most important stakeholders in the sectors of renewables, fuel cells, and corresponding technologies were interviewed. The Hanover fair offered a good opportunity to interview many of these stakeholders. If necessary, these interviews were updated.

Attachment 1 lists the institutions, which were interviewed.

6 Relevant Stakeholders in Germany

- **Identification**
  - **Producers of Fuel Cell Systems**

The biggest producers of fc–heating installations in Europe in 2005/2006 were:

- BBT Thermotechnik GmbH/Germany (1)
- Vaillant GmbH/Germany (2)
- BAXI/Great Britain (3)
- MTS/Italy (4)
- Ferroli/Italy (5)

(s. attachment Bosch_20070326_marktreport_dt_final.pdf, page 47)

Out of these, BAXI INNOTECH GmbH, BBT Thermotechnik GmbH, and Vaillant GmbH are members of the Initiative Brennstoffzelle – and they are potential suppliers of fuel cell systems. In addition to these companies the following producers of fcs (also members of the Initiative Brennstoffzelle) have been contacted:

- Hexis AG/Switzerland
- RWE Fuel Cells/Germany
- Viessmann Werke GmbH & Co KG/Germany

  - **Users of these Systems**

The following utility companies are also members of the Initiative Brennstoffzelle. They are:

- E.ON Ruhrgas AG, Essen
- EnBW Energie Baden-Württemberg AG
- EWE AG Oldenburg
- MVV Energie, Mannheim
- RWE AG
- VNG Verbundnetz Gas Aktiengesellschaft, Leipzig

E.ON, RWE, and EnBW are among the biggest power suppliers in Germany. So is Vattenfall, even though the company is no member of the Initiative Brennstoffzelle. EWE and MVV are smaller suppliers. VNG is a gas supplier.

- **Producers of Energy Carriers from Sustainable Sources**

Bio-Ethanol/Bio-Methanol

No bio-*methanol* is or will be produced in the middle-term future from bio-resources in Germany. *Südzucker Bioethanol GmbH produces bio-ethanol* on a technical scale in Zeitz in East Germany. The company is the biggest producer of bio-ethanol in Germany. It aims at the automotive sector, which competes with fuel cells for this renewable.

Biogas

Upgraded biogas (SNG) as a renewable energy source (for fuel cells etc.) could play a prominent role in the future, if the grids are opened for SNG by law. So far, some energy suppliers (mostly middle sized with own grids) are interested (e. g. VNG Verbundnetz Gas Aktiengesellschaft, Leipzig, see below).

Hydrogen from Wind Energy

The production of hydrogen from *surplus wind energy* isn't much of a topic for the utility companies. First choice for such hydrogen would be in the mobility sector (e. g. Vattenfall, but EWE/Oldenburg doesn't rule out that surplus power might be used to produce hydrogen for residential fuel cells in individual cases in the future.)

- **Analysis and Involvement**
  - **Producers of Fuel Cell Systems**

The following spreadsheet shows the involvement as well as the fuel cell prototypes of these companies in the current phase of field tests:

BAXI INNOTECH	Low temperature PEMFC	1.5 $kW_{el.}$ and 3 $kW_{th.}$	Single – family houses
BBT Thermotechnik	The company, member of the Bosch group, works very reticently. It asked for a questionnaire, however answered with a general statement instead. It concentrates on energy-efficient projects, which can be implemented hopefully within a short period (Stirling engine), but watches fuel cells closely (s. attachm. Bosch_PI_1013_Mikro_KWK_auf Anfrage_final.pdf).		
Hexis	SOFC system "Galileo 1000 N"	1 $kW_{el.}$ and 2.5 $kW_{th.}$	Single – family houses
RWE Fuel Cells	The company has been testing systems from Idatech and Sulzer Hexis. Actually RFC was monitoring fuel cells for RWE, its mother company. Lately the company has been decreasing its activities (s. below).		
Vaillant	Low temp. PEMFC from Plug Power Coming soon: SOFC with Webasto	4,6 $kW_{el.}$ and 7-8 $kW_{th.}$ 1-2 $kW_{el.}$ and 1-2 $kW_{th.}$	apartment houses and small office buildings, Single – family houses

Viessmann	Low temperature PEMFC	2 $kW_{el.}$ and 3.5 $kW_{th.}$	Single – and double - family houses

The interviewed companies (for details see attachments) give a representative picture of potential suppliers of fuel cell systems in Germany.

- **Users of these Systems**

The following spreadsheet shows the involvement of the utility companies, which are partners of the fuel cell producers in the current phase of field tests:

E.ON Ruhrgas AG, Essen *)	The company will participate in the experience gained with fuel cells, and consult her clients with no intention to use fuel cells, since EON doesn't supply the end user. Eon hasn't looked at the possibility to use surplus wind power to make hydrogen. This may become a topic, when the company will start operating off shore wind parks.
EnBW Energie Baden-Württemberg AG *)	EnBW is actively engaged in testing fuel cell systems. So far the company is operating 16 FCS from Hexis (Galileo generation/SOFC)(1 $kW_{el.}$), 1 FCS from Vaillant and 1 FCS from Baxi-Innotech
EWE AG Oldenburg *)	EWE wants to keep a reputation as an innovative and environmentally sensitive utility company. Fuel systems are expected to fit into that category.
MVV Energie, Mannheim *)	MVV has qualified for the "15 minutes back-up". This means that the company can provide a minimum of 15 MW (regulated) for at least 15 minutes in case of a black out. In the future fuel cells may play a roll in this reserve scenario.
RWE AG *)	Until lately the company was very active in testing fuel cells. Recently it lowered its activities in this field, looking generally at innovative CHP systems (efficient ICE or Stirling engines) and at SNG.
VNG Verbundnetz Gas Aktiengesellschaft, Leipzig *)	The company has founded a "Biogas GmbH" just recently. Having already looked at 5 fuel cell systems from Sulzer Hexis and two from Vaillant, VNG AG at present is testing a PEM fuel cell system from the Riesa Brennstoffzellen GmbH. Further tests with Baxi´s fuel cells are planned.

*) All companies are members of the German Initiative Brennstoffzelle.

- **Producers of Energy Carriers from Sustainable Sources**

<u>Bio-Ethanol/Bio-Methanol</u>
<u>Biogas</u>
<u>Hydrogen from Wind Energy</u>
} See above

- **Market Development**

It is the *objective* of the present field tests to achieve a validated technology by 2015, which comprises the following best technical solutions:

- Improve the availability of the system comparable to today's systems
- Improve the lifetime of the systems to 40 – <u>60.000</u> hrs (PEMFCs as well as SOFCs).
- Simplify the systems and gain robustness
- Decrease degradation of the systems over time
- Decrease the size of the systems
- Reduce costly material

The *target of the field tests* can be summarized as a simple marketing strategy:
Gain experience with the number of systems necessary to fulfil the technical expectations (lifetime, availability, etc.) to participate in an emerging market by 2015 and reduce costs by 2020 to have a competitive edge on conventional systems.

- **What steps need to be taken to develop he market?**

Fuel cells:
As mentioned above, the producers of fuel cell systems and the utility companies have closed ranks in the *Initiative Brennstoffzelle* (Initiative Fuel Cell, www.initiative-brennstoffzelle.de) out of a common interest. Additionally, they have outlined their plans to develop the market in the *German National Development Plan.* And – as it looks now - they seem to be successful in getting funding from the *German innovation program* to achieve their targets.

For our center this means that we keep a close eye on that the stakeholders will not tire in their effort to achieve their goals. We will make the contacts and the knowledge of our network available to support the stakeholders in their efforts.

We also will make clear towards politics that fuel cells have a big potential, but still have some way to go to overcome barriers (technically, price wise, and against available products). Therefore they need support (e.g. favourable feed in tariffs and/or funding).

Sustainable feed for fuel cells:
And we have to find intelligent suggestions for sustainable fuel cell feed. Seeing this over time, the first step right now is natural gas. The second step might well be synthetic natural gas, as I've stated on our website:

In general the capacity of the fuel cell systems for residential use follows the electrical demand in Germany. This average demand is at least 0.5kW (for passive energy homes) with a heat demand exceeding the corresponding heat production of the fuel cell in wintertime. This means that an additional burner has to be installed for the demand of extra heat. At present this burner uses natural gas, which also is the feed for the reformer for the PEMFC.
Therefore in countries with a natural gas grid it makes sense to feed upgraded biogas (or sewage gas) into the grid to make it available for use in fuel cells – among other things - as a first step towards sustainability.

Further down the road we might see hydrogen from wind and bioethanol. Here we have to look into the ecological efficiency of these renewables, spread the word, convince the opinion leaders and stakeholders, and get them together by networking, where needed.

- **Summary**

The following table shows the actors as well as their preconditions.

	Stake	Interest	Power	Organisation	Information	Access	Knowledge
BAXI INNOTECH	fuel cells	√	√	√	√	√	√
BBT Thermotechnik	fuel cells	limited	√	√	√	√	√
Hexis	fuel cells	√	√	√	√	√	√
RWE Fuel Cells	fuel cells	Declining	√	√	√	√	(√)
Vaillant	fuel cells	√	√	√	√	√	√
Viessmann	fuel cells	√	√	√	√	√	√
E.ON Ruhrgas AG	utility comp.	(√)	√	√	(√)	(√)	(√)
EnBW AG	utility comp.	√	√	√	√	√	√
EWE AG	utility comp.	√	√	√	√	√	√
MVV Energie	utility comp.	√	√	√	√	√	√

RWE AG	utility comp.	Declining	√	√	√	√	√
VNG Verbundnetz Gas AG	utility comp.	√	?	?	√	√	√
Südzucker Bio-ethanol GmbH	bio-ethanol producer	Emphasis on mobility	√	√	(√)	(√)	(√)

The evaluation was gained through interviews and may be subjective.

For producers of fuel cells, the engagement seems to be considerable, except for RWE Fuel Cells, where it seems to be declining. It's difficult to judge BBT Thermotechnik, since the company works very reticently. Through their partnership with the utility companies (Initiative Brennstoffzelle) they all have a good marketing access.

As for the interviewed utility companies, including the biggest ones in Germany, the engagement seems to be considerable, too. Only the interest of RWE AG seems to be declining.

The joint effort of users and producers (of fc–systems) in Germany (Initiative Brennstoffzelle) has led to a defined plan of market penetration with targets, costs and estimated number of fuel cells (Phase I/2007 - 2010: 450 systems, phase II/2011 – 2015: 2250 systems, see figure 1), which hopefully will be honoured by the German national development plan. Our center will support this effort towards politics and line out that fuel cells have a big potential, but still have some way to go to overcome barriers (technically, price wise, and against available products).

Our favourite *sustainable feed for fuel cells* for the near future is SNG (synthetic natural gas).

In countries with an established natural gas grid like Germany it makes sense to feed upgraded biogas (or sewage gas) into the grid to make it available for use in fuel cells – among other things - as a first step towards sustainability. So *SNG (from biogas)* could play a prominent role in the future, if the grids are opened for SNG by law. So far, some energy suppliers (mostly middle sized with own grids) are interested (e. g. VNG Verbundnetz Gas Aktiengesellschaft, Leipzig, or Stadtwerke Esslingen). IBBK may have more information on this topic. Other feed like bioethanol or hydrogen from wind energy may come later down the road as outlined below:

As mentioned in earlier reports, Südzucker Bioethanol GmbH, the biggest *bio-ethanol* producer in Germany seems to aim at the automotive sector.

The production of hydrogen from *surplus wind energy* isn't much of a topic for the utility companies. First choice for such hydrogen would be in the mobility sector again except for residential fuel cells in individual cases (e. g. Vattenfall, EWE/Oldenburg). So the efforts on the side of fc–systems (users and producers) for residential areas are considerable, and for sustainable feed they seem to be picking up, but more has to be done.

7 Attachments
Attachment 1: List of Stakeholders, who were interviewed
Attachment 2: Figure 1: German National Development Plan
Attachment 3: Memos (Interviews and Documents)

* * *

Attachment 1: List of Stakeholders, who were interviewed

Contacts Fuel Cell Systems and Utility Companies:

BBT Thermotechnik GmbH/Manufacturer
Thomas Pelizaeus — Tel.: +49 (0) 7153 - 306-2261
Fax: +49 (0) 711 - 811 - 516 22 61 — thomas.pelizaeus@de.bosch.com
Address: BBT Thermotechnik GmbH
Sophienstraße 30-32 — 35576 Wetzlar

BAXI INNOTECH GmbH/Manufacturer (PEM/1,5 $kW_{el.}$)
Frank Jüngerhans — Tel.: +49 (0)40 - 23 66-76 30
Fax: +49 (0)40 - 23 66-76 01 — f.juengerhans@baxi-innotech.de
Address: BAXI INNOTECH GmbH
Ausschläger Elbdeich 127 — 20539 Hamburg

E.ON Ruhrgas AG, Essen/Utility Company (1,5 bis 4,5 $kW_{el.}$ PEM-BZ der Fa. Vaillant)
Helmut Roloff — Tel.: +49 - 2 01 - 1 84-39 52
Fax: +49 - 2 01 - 1 84-43 51 — helmut.roloff@eon-ruhrgas.com
Address: E.ON Ruhrgas AG, Essen
Huttropstraße 60 — 45138 Essen

EnBW Energie Baden-Württemberg AG/Utility Company
Dirk Ommeln — Tel.: +49 (0) 7 21/63-123 20
Fax: +49 (0) 7 21/63-126 72 — d.ommeln@enbw.com
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EWE AG Oldenburg/Utility Company
Nina Zipplies — Tel.: +49-4 41 - 8 03-1811
Fax: +49-4 41 - 8 03-1895 — nina.zipplies@ewe.de
Address: EWE AG Oldenburg
Tirpitzstraße 39 — 26122 Oldenburg

Hexis AG/Manufacturer (1 $kW_{el.}$ SOFC)
Volker Nerlich — Tel.: +41 (0) 52 262 - 82 07
Fax: +41 (0) 52 262 - 63 33 — volker.nerlich@hexis.com
Address: Hexis AG
Hegifeldstrasse 30 — CH-8404 Winterthur

MVV Energie/Utility Company
Roland Kress — Tel.: (0621) 290-3413
Fax: (0621) 290-2860 — r.kress@mvv.de

Address: MVV Energie, Mannheim
Luisenring 49 68159 Mannheim

RWE Fuel Cells/Utility Company (4,6 $kW_{el.}$ PEM system from IdaTech)
Anja Ludwig Tel.: +49 (0) 201 - 12 20-217
anja.ludwig@rwe.com
Address: RWE Fuel Cells
Gutenbergstraße 3 45128 Essen

Vaillant GmbH/Manufacturer (with Plug Power)
Alexander Dauensteiner Tel.: +49 (0) 21 91 - 18-25 06
Fax: +49 (0) 21 91 - 18-725 06 alexander.dauensteiner@vaillant.de
Address: Vaillant GmbH
Berghauser Straße 40 42859 Remscheid

Viessmann Werke GmbH & Co KG/Manufacturer (2 $kW_{el.}$ PEM system)
Rainer Dippel Tel.: +49 6452 703075
Fax: +49 6452 706075 DpR@viessmann.com
Address: Viessmann Werke GmbH & Co KG
Viessmannstr. 1 35107 Allendorf

VNG Verbundnetz Gas Aktiengesellschaft/Gas Provider (Cooperation with several manufacturers)
Silvio Grafe Tel.: +49/3 41/4 43-2844 (0172/3431764)
Fax: +49 - 3 41 - 4 43-29 19 silvio.grafe@vng.de
Address: VNG Verbundnetz Gas Aktiengesellschaft, Leipzig
Braunstraße 7 04347 Leipzig

Contacts Renewables:

Bioethanol:
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Dr. Jörg Bernard Tel.: 06359/803-483
joerg.bernard@suedzucker.de

Wind energy
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Fax: 04841 / 89 221
www.wind-energie.de

Landesbüro Schleswig-Holstein
Querweg 4
Tel: 04841 / 89222
Email: a.feddersen@bwe-regional.de

BEE Bundesverband Erneuerbare Energie e.V.
Teichweg 6 D-33100 Paderborn
Tel: +49(0)52 52 - 939 800 Fax: +49(0)52 52 - 529 45
www.bee-ev.de

Attachment 2: Figure 1: German National Development Plan

(Nationaler Entwicklungsplan, Version 2.0 of February, 2007, pp. 12 - 16.)

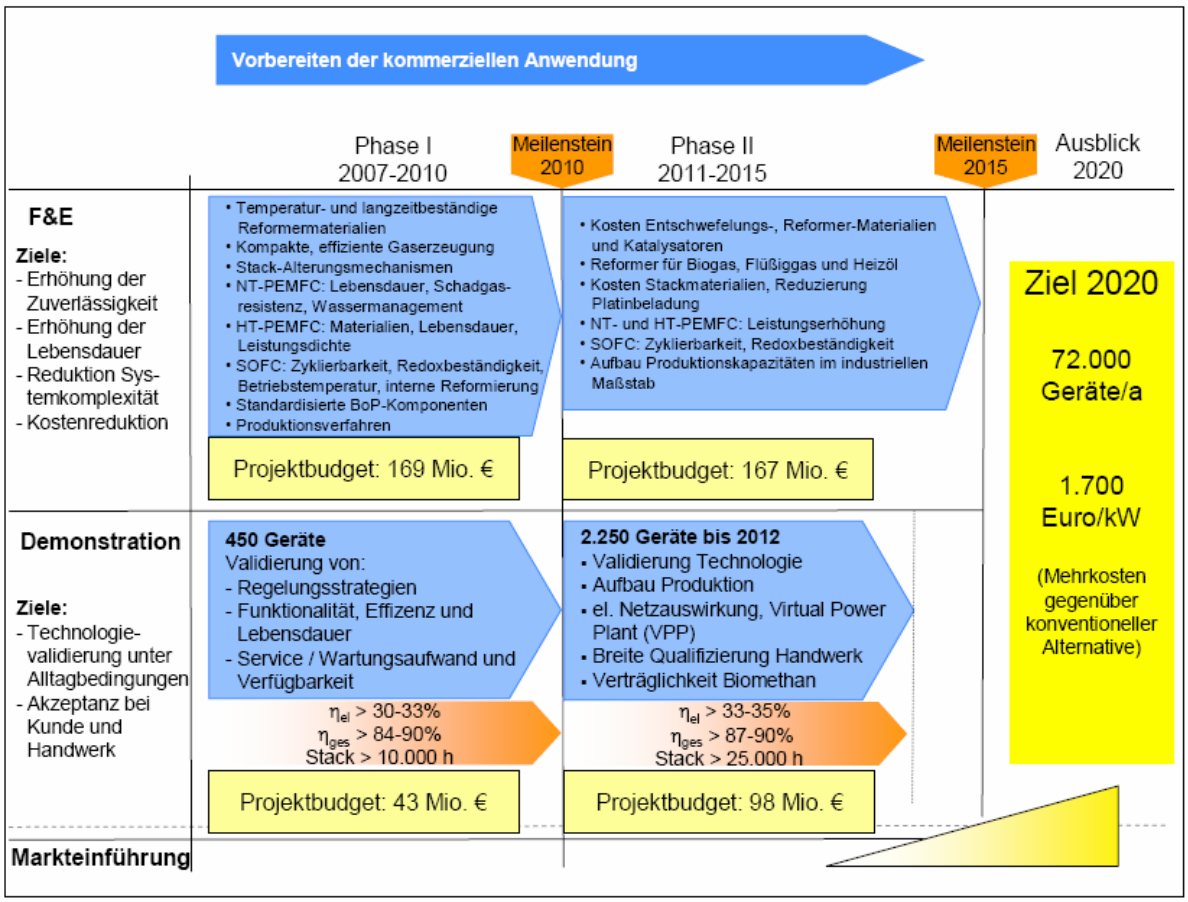


Abbildung 4-1: Entwicklungsplan für stationäre Anwendungen in der Hausenergieversorgung

WP 3

Regional Market Development Plans

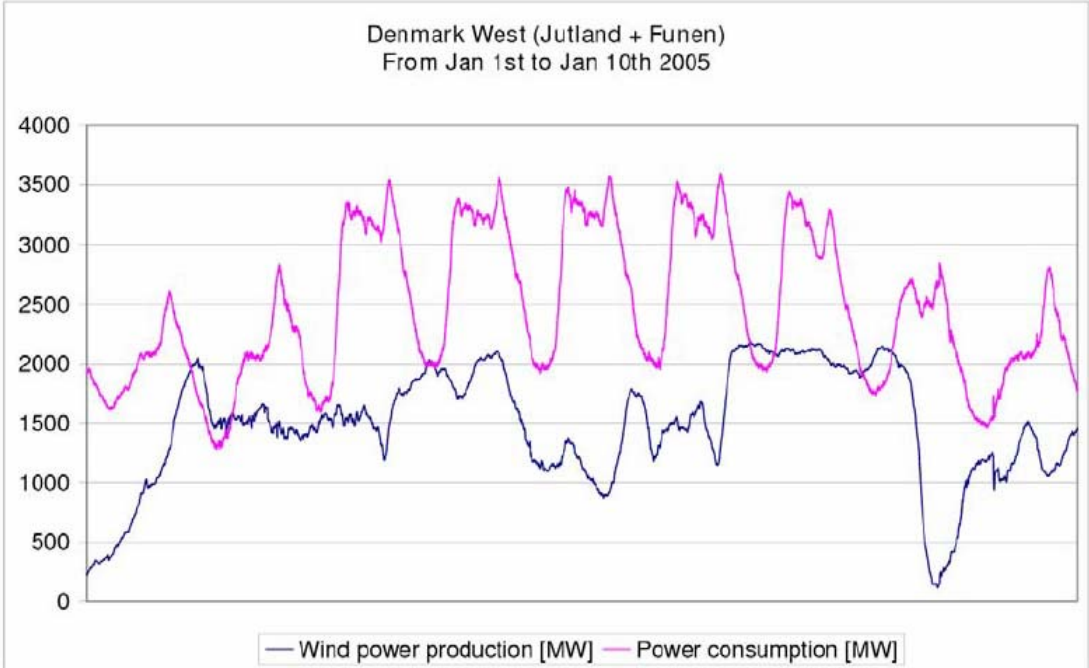
Ethanol/methanol from bio–resources / Jutland, Denmark

Martin Møller

Contents

1 General Description of the market development plan

The idea with the ethanol and methanol case is a flexible and centralized energy plant that can store energy, by absorbing electricity from the grid. The plant exists somewhere within a grid that is having problems with fluctuating energy. A specific place could be the western part of Denmark, which has a relative high share of wind power installed. When more than planned electricity from the wind farms is produced, then the electricity prices drops to very low figures, and the surplus electricity is exported out the region.



As can be seen on the above graph, it is a huge challenge to balance the power grid, and in certain periods the electricity production from wind exceeds the power consumption in the region. The central power plants however also needs to operate, in order to on a very short notice to provide backup power if the wind production suddenly drops. Furthermore, they are needed in order to control the frequency. Due to the above there are often surplus of electricity in the western part of Denmark.

The concept of the centralized energy plant is described in WP2, but the principles are:

1. Ethanol is produced from a given biomass in a fermentation process
2. The non fermentable[2] part of the biomass is gasified with oxygen into to H_2 and CO
3. The O_2 is delivered from an O_2 storage fed by an electrolyser
4. The hydrogen from the electrolyser is mixed with the CO and H_2 from the gasifier
5. The CO and H_2 is converted into methanol
6. The electrolyser is only operated when there is “surplus” electricity[3]

Either the produced methanol or ethanol can be used as feed for a micro CHP, based on fuel cells[4]. The case is based on centralized methanol reforming, in a cluster of around 300 households. The fuel cells will operate on hydrogen, and will be identical with the ones used in the wind case. The difference between the wind case (wind to hydrogen, case 1 from WP2) and the present case is that the wind energy is stored in liquid methanol, instead of

[2] In general all kind of biomass and water can be used in this gasification process
[3] In reality it will be operated, when the cost of electricity is below a certain level
[4] In WP4 it has been concluded that methanol instead of ethanol will be used in the fuel cell.

gaseous hydrogen. The advantage is, that methanol is much easier to store than gaseous hydrogen. Furthermore, the oxygen from the electrolyser, can effectively be used in a gasifier that converts biomass into hydrogen and carbon monoxide. The electrolyser and gasifier do not have to be installed closed to the end-user, but just have to be installed somewhere that is connected to the same electricity grid. The produced hydrogen (stored in methanol) can easily by truck be transported to the areas of households equipped with micro CHP. This distance between the end user and the plant, also gives the possibility to take advantage of the economy of scale, by constructing rather large energy plants, with say 200-600 MW of installed electrolyser capacity. From a grid regulation point of view, the concept gives the same possibilities as the wind case (case 1), but it will be easier to administrate one large "regulating plant", instead of hundred communities operating their own common 1 MW electrolyser. Furthermore, if a central large electrolyser plant is located close to a large offshore wind farm, there will be huge savings in the construction of the high voltage grid. These savings will not be obtained if the regulating electrolysers are placed decentralized.

2 Brief description of the regional market

2.1 The appropriateness of the fuel mix, straw and wind electricity

As argued above there is a need to control and regulate the increasing amount of wind power in the region, and the purposed use of electrolysis has a potential. However in order to make use of the produced oxygen, the electrolyser process shall be combined with an oxygen consuming process. Such a process could be a gasification process that converts carbon-containing materials into CO and H_2 that can be further synthesized into liquid fuels. It is most feasible to use a pressurized gasifier as the downstream synthesis requires elevated pressures. The carbon containing material could either be coal, oil, NG, biomass or waste, but only biomass or waste is considered sustainable. Furthermore it should be possible to pressurize the biomass or waste, in order to introduce it into the gasifier. The leftover from an bio ethanol plant is pumpable, and hence it can easily be introduced in a pressurized gasifer.

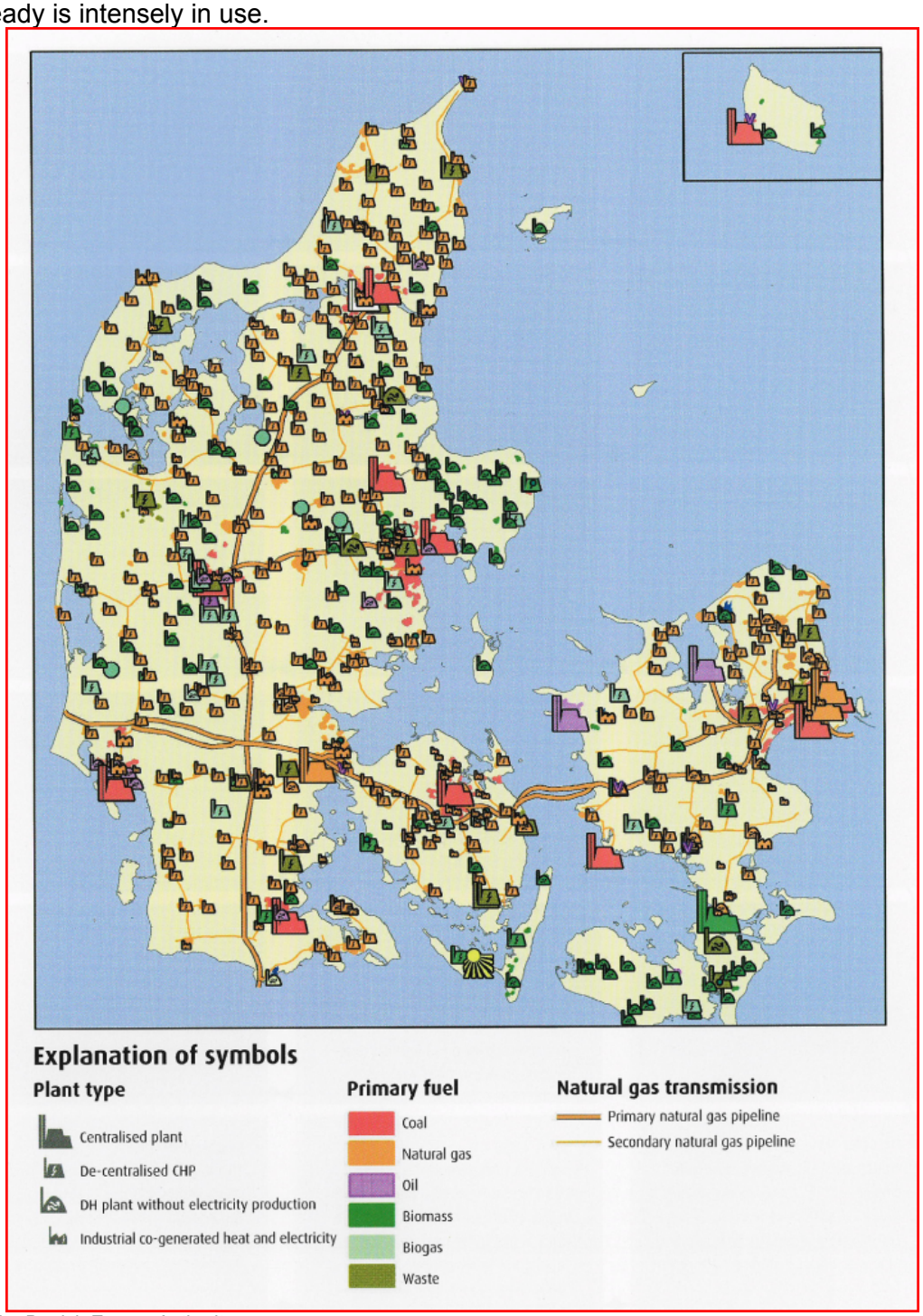
Denmark already has an infrastructure for handling and selling straw, and around 1 mill. tons of straw per year is already used in various large boilers in Denmark. The potential use of straw probably includes an additional 2 to 3 million tones annually so there is hence both an existing infrastructure as well as an additional potential.

Developers of second-generation ethanol plants in Denmark are also focused on using straw as raw material. Hence it can be concluded that the use of "wind electricity" and straw is very appropriate for Denmark.

2.2 Domestic heat and electricity demands per dwelling

Denmark has a strong tradition for using combined heat and power, and all the major cities and many smaller have an infrastructure for district heating. Either the heat is delivered from large centralized power plants of say 400 MW, or by smaller decentralized gas, waste or biomass fired units. This is a huge competitor for micro CHPs, due to the fact that the infrastructure is already there, and due to economy of scale. Hence the only place where micro CHPs have a possibility to enter the market will be in areas of new housing development or less densely populated areas.

The below figure illustrates the heat supply in Denmark, and it can be seen that district heating already is intensely in use.



Source: The Danish Energy Authority

The point of origin in this concept will hence be new houses constructed in new areas, or old houses that are placed far from a district heating system. However, as the concepts relays on a cluster of say 300 dwellings sharing a common methanol reformer, focus should be on new housing development. In order to save the heat required, the new houses will be constructed as passive houses, with a minimum of heating required. Details can be found in the calculations in WP4.2.

2.3 The performance of the energy system

As the advantage of combining heat and power production in Denmark already is utilized, it will be impossible to compete with the exiting system in terms of efficiency. The key parameter instead has to be flexibility or cost. As already mentioned the system has the potential to support the Transmission System Operator with balancing the grid, and hence it has the potential to introduce some flexibility into the energy system. On the other hand the micro CHP is operated according to the heat demand, but as it also produces electricity, and can also contribute to bring the grid in unbalance. In order to understand the fully effect, a huge study of the future energy system is needed.

2.4 Summary of the cost for the system

In WP4 the cost for the end user using the micro CHP has been calculated (see WP4.3 for further description).

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	1043	1043	1043	1043	1043	1043
Value of heat production from CHP Euro	382	382	382	382	382	382
Value of CHP production per year	1.424	1.424	1.424	1.424	1.424	1.424
Value of CHP production minus cost of hydrogen, Euro per year	-650	-1.700	-1.485	-2.535	-1.135	117

As discussed in WP4, the system with micro CHP does not seem to be feasible for an end user point of view, and as it most realistic will more than double the energy bill for the end user, it will be difficult to realize the project. One has to remember that the system already has been relieved from all taxes except VAT. Hence if the projects has to be realized heavily support from ie. Government funding is needed.

3 Identification of Relevant Stakeholders

Based on the above general description and the work done in WP2 and WP4, the relevant stakeholders are identified as the following groups.

1. Producers of fuel cell systems
2. End-users of these systems, including communities
3. Producers of the energy carrier, in this case methanol
4. Suppliers of electrolysers
5. Suppliers of methanol reformers
6. The TSO Energinet.dk and the balance responsible players

3.1 Producers of Fuel Cell Systems

The two obvious stakeholders in Denmark will be IRD and Dantherm, but as all the 3 cases are based on using “pure” hydrogen in PEM fuel cells, the FC stakeholders identified in the wind and biogas case will be the same.

3.2 End-users of these systems, including communities

In Denmark there are several communities interested in the systems, and as previously mentioned the system installed at the end-user will be identical in all the 3 cases, and hence the stakeholders will be the same. However with the calculated additional cost for the end-user, some of the projects are doubtful.

A. H2PIA

The H2PIA-project is still in a planning/funding phase, and no final decisions have been made in regards to which type of fuel cells to use in the different parts of project. If sufficient funding is attained the project consisting of 200 households will most likely materialize in 2010-12. The houses are planned to be passive houses; which means that the houses are designed to have a maximum annual heat consumption of 15 kWh/m^2.

B. New project

A newly established project in Herning consisting of 16 household units (four small apartments in each) is to be built in the autumn of 2007. The households are to be powered and heated by high temperature (HT) PEM FCHS (½ kWe + ½ kW heat in each unit). The supplier of the FCHS has been chosen.

C. Nakskov/Sønderborg

The Nakskov/Sønderborg project will consist of 100 households (phase 3). The project is testing 4 different FCHS technologies: low temperature PEM FC units fuelled with pure hydrogen; HT-PEMFC units with reformer, SOFC units with catalytic partial oxidation and SOFC units with reformer. Phase 3 is planned to commence in 2009/2010.

D. Nólsoy

The Nólsoy project on the Faroe Islands is a 100 % renewable energy project based on wind power (with backup diesel generators). The island consists of 105 households plus a school, industry facilities, a nursery etc. The project is still in an early development phase. The organization behind the project – the Faroese Earth and Energy Directorate is currently working on establishing a consortium to carry out the project, as well as discussing whether to work with micro CHPs or central heat/electricity production.

3.3 Producers of the energy carrier, in this case methanol

The potential use of methanol in these systems will in the short to mid term be very limited compared to the world production of methanol, and hence it is not estimated that the traditional methanol producers will be interested. But on the longer term the methanol producers are interested in increased methanol consumption by increasing the number of different applications that can use methanol. The proposed methanol production concept in WP2, is new and contains a rather large electrolyser unit, that can be used to regulate the power sent to the grid. Power producers as DONG Energy will be interested in having a tool that can regulate the power sent to the grid, because they also operate wind farms, which provides fluctuating energy. Other power companies as Vattenfall, EON, RWE might also have similar interest. With the low electricity prices Denmark has experienced in 2007, the prices are just around the marginal production cost. In such a situation the entire contribution margin, is made up by selling regulating power, which makes the electrolyser concept very interesting.

3.4 Suppliers of electrolysers

These are discussed by HIRC, in the Denmark/wind case.

3.5 Suppliers of methanol reformers

Methanol reformers in the size suitable for clusters of 150-300 houses are already commercially available from i.e. Haldor Topsoe A/S or Mitsubishi Gas Chemical. In the short to medium term the potential sales of such systems will be limited, and hence the interest will be

limited. Such small systems are not core business for these companies, and hence there long term interest will also be limited. If however a market for such systems starts to explode, the above companies might adapt their business to the new situation, but it's unlikely that the will provide a market pull.

3.6 The TSO Energinet.dk and the balance responsible players

As already mentioned several times both in WP2 and WP4, and in the wind case, the balance responsible in Denmark are interested in a tool that can be used to regulate the power production from fluctuating sources as wind energy. For the TSO it is however not important whether the produced methanol is sold to the world market, or feed into a micro CHP. The importance is whether the concept can be used to balance the grid. Actually the micro CHP may worsen the grid balance, because the micro CHP is operated according to the heat demand, and as it also produces electricity, it actually contribute to making the grid more instable. From the graphs and calculations in WP4, it can be observed the chosen FC have to run continuously to supply the needed heat. In the majority of the months the production matches the potential production. In average the CHP is only closed down 0.75 hours / day, in order to balance the import/export out of the house.

4 Authorities setting framework conditions

These will be well described in the Denmark/wind case in WP3.

5 Summary

Denmark has a need to work seriously with balancing of the grid, which is caused by the high share of wind power installed in the system. The geographical placement of new wind farms in the grid is crucial in order to lower the investment in reinforcement of the grid capacity. If all the wind farms are placed in a certain region, the grid will experience serious bottlenecks. This can be solved by installing power consuming units as electrolysers in close physical distance from the region of where the wind power is produced. Many small electrolysers spread around the country, will not have the same effect, except if all the wind farms also are spread all over the country. Politically this is hard to achieve due to the public opinion, that requires that the new wind farms are installed offshore, where they don't harm their own backyard. Also the fact, that a large centralised electrolyser plant benefits from economy of scale, and that it will be possible to utilise the produced oxygen, which is very difficult in decentralised scenarios, disfavours the use of micro CHP.

Also the use of micro CHP seems to be very costly, and as they cannot compete in terms of efficiency with existing district heating systems, and centralised electrolyser plants, they have to struggle to enter the market.

If the perspective is to balance the power grid, in order to increase the amount of wind share, one should focus on larger electrolyser plants, where the oxygen can be used, and economy of scale can be obtained.

If the purpose is to develop fuel cell systems as i.e. backup batteries, one should continue to promote micro CHPs, as this will push the development of fuel cell into a commercial product, that hopefully can compete, due to economy of mass production. If the later is the case, the major stakeholders will be fuel cell and system producers as Dantherm Power and IRD.

WP 3
Regional Market Development Plans

Ethanol & Methanol / hydrogen in Iceland
Thorsteinn I. Sigfusson

UNIVERSITY OF ICELAND

Contents

1. General Description of Market Development Plans

As was pointed out in WP2 the application of stationary fuel cells operating on hydrogen and providing CHP has a limited interest in Iceland. This is mainly caused by the available geothermal energy for heating which accounts for over nine tenths of space heating in the country and almost general access to grid power which again is based on low cost hydroelectric or geothermal turbine electricity.

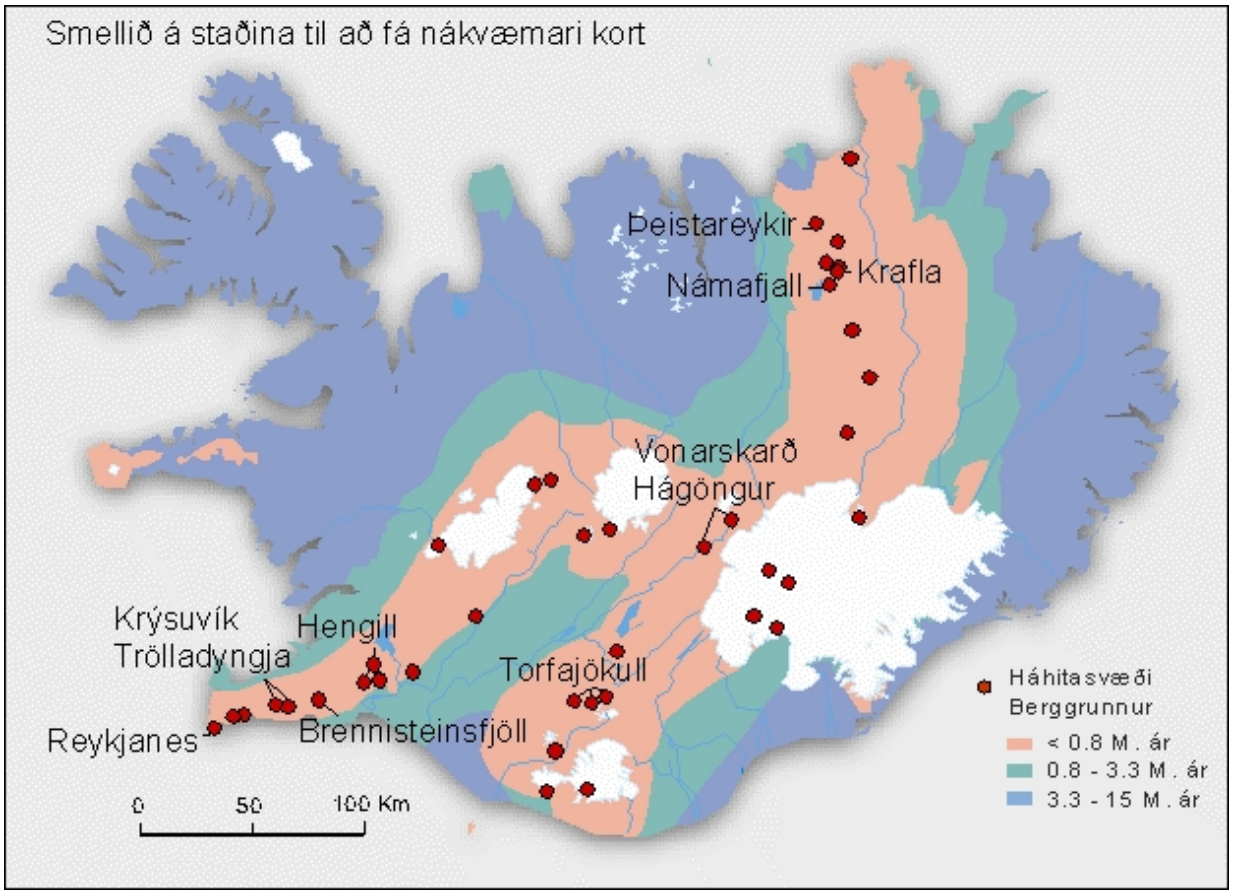


Figure 1. Main high-temperature geothermal sources in Iceland, figure adapted from the Icelandic National Energy Authority. The geothermally colder areas are in the NW corner of the picture as well as on the Eastern fjords.

There are areas outside the regular grid-system and situated in geothermally cold areas where the present project has focused on the possibility of powering a group of leisure houses with methanol made from a process being investigated from carbon emissions form the heavy industry in Iceland combined with hydrogen in a number of processes described below. One of them is simply methanol.

2. Direct hydrogenation of CO_2/CO

In the table below the enthalpy ($\Delta H°$) changes of some of the reactions involving CO_2 and fuel are shown. The main reason for the relatively favourable values of $\Delta G°$ for the hydrogenation reactions is that water is produced.

Equation no.	Reaction	ΔH° [kJ/mol]
1a*	$CO_{2\,(g)} + 3H_{2\,(g)} \rightarrow CH_3OH_{\,(l)} + H_2O_{\,(l)}$	-137.8
1b**	$CO_{2\,(g)} + 3H_{2\,(g)} \rightarrow CH_3OH_{\,(g)} + H_2O_{\,(g)}$	-46.2
2*	$CO_{2\,(g)} + 4H_{2\,(g)} \rightarrow CH_{4\,(g)} + 2H_2O_{\,(l)}$	-259.9
3*	$CO_{\,(g)} + 2H_{2\,(g)} \rightarrow CH_3OH_{\,(l)}$	-131.6
4**	$2CO_{\,(g)} + 4H_{2\,(g)} \rightarrow CH_3CH_2OH_{\,(g)} + H_2O_{\,(g)}$	-256.1
5***	$2CH_3OH \rightarrow CH_3OCH_3 + H_2O$	23.4
6****	$(2n+1)H_2 + nCO \rightarrow C_nH_{2n+2} + nH_2O$	170

*Xiaoding & Mouljin
**Mignard & Pritchard
***Semelsberger, Borup & Greene
****Wender

3. The most likely production methods

Carbon dioxide can be hydrogenated into methanol or methane according to equations 1 and 2 above. Methane, which is a gas at atmospheric pressure and temperature, can be combusted in a special gas-combustion engine or gas tubes but it is more difficult to transport than liquid fuel. Economically it is not likely to be attractive as a product from carbon dioxide and hydrogen gas since it is cheaper than the hydrogen it is produced from]. Methane is often used as a base in methanol production but is then usually obtained from natural gas.

The production of methanol from flue gas is not a new idea and projects have been carried out all over the world; in Scotland and Korea among others. Mignard et al simulated a plant, producing methanol from CO_2 through hydrogenation. The plant contained; a CO_2 extraction with monoethanolamine (MEA) cycle, an electrolyser part – splitting water into H_2 and O_2, a methanol production part and a separation part. The reactor was a plug flow reactor, where the gases were to be mixed and reacted over the catalyst $Cu/ZnO/Al_2O_3$. The operation was retained with inlet temperature of 230°C, inlet pressure 50 bar, a recycle ratio of 7.9 and minimum purity of methanol 99%. According to the simulation the overall efficiency of conversion (kW_{out}/kW_{el}) reached 68% if waste heat was available (lower heating value of methanol 19.93 MJ/kg). The catalyst, $Cu/ZnO/Al_2O_3$ was tested by and the observed equilibrium yield at pressure of 50 bars was 22%. The feed gases were CO_2 and H_2 and the low conversion to methanol was due to inhibitory effect of water, produced in the reaction through Reverse Water-Gas shift (RWGS) reaction. Today better catalysts have been developed such as $Cu/ZnO/ZrO_2/Al_2O_3/Ga_2O_3$ showing better longevity, selectivity and activity than the $Cu/ZnO/Al_2O_3$ and up to 46% better space-time yield.

At the catalyst laboratory of Korea Institute of Science and Technology a research on catalysts to form methanol carbon dioxide has been performed. The catalyst was $Cu/ZnO/ZrO_2/Ga_2O_3$ (5:3:1:1) and by pre-treating the inlet gas with a RWGS reactor the yield increased from 69% to 89%. The reason is the deactivation effect the presence of water has on the catalyst. When carbon monoxide is present in the reaction mixture, it reacts with water, forms CO_2 and hydrogen and regenerates the active sites on the catalyst [This process was named the CAMERE process (carbon dioxide hydrogenation to form methanol via a reverse-water-gas-shift reaction) and the inlet composition was 40% CO_2 and 60% CO with a H_2 ratio of 2.4. One of the major advantages with the CAMERE compared to direct synthesis of methanol was the reduction of the recycle gas volume. To maintain the proper partial pressure of the feed gas, a portion of the recycle gas should be purged out causing hydrogen losses. As a result the CAMERE process increased methanol production by 29% with the same amount of hydrogen.

4. A devoted company is emerging in Iceland

The new company Carbon Recycling International has as a goal to develop methanol in the first of its steps towards general synthetic fuels. The main catalysis technology used in the

CRI work is obtained from Halldor Topsoe of Denmark which makes the pathway very interesting seen from the point of view of this present EIE project.

The company sees its work in the way described in the below figure.

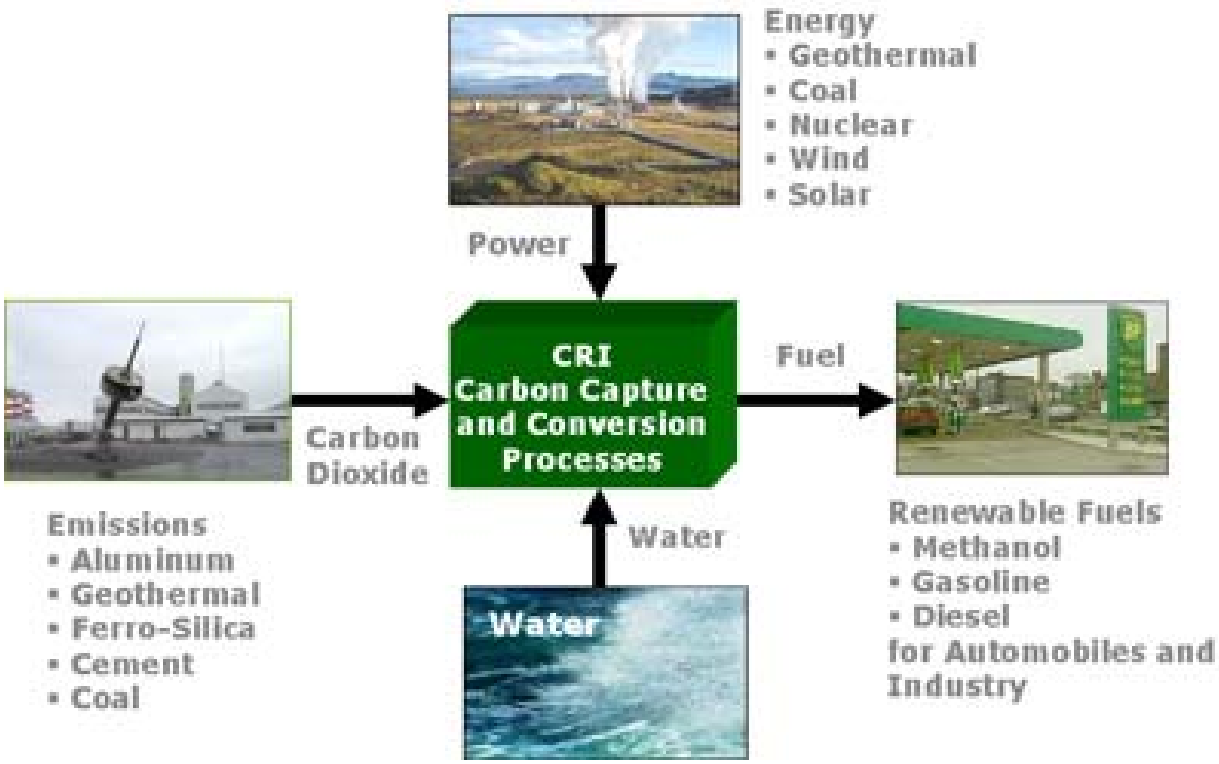


Figure 2. In the figure above we can see on the left hand side the most likely industrial sources of CO_2. CRI plans to capture the carbondioxide from geothermal gas in the first instance and later from a ferrosilicon smelter.

The electric energy for the process is in Iceland expected to come from geothermal. And the renewable fuels so obtained are expected to be methanol and other possible derivatives.

The main stakeholders of the methanol production process are besides CRI, the Landsbankinn bank, the Sudurnes Municipal heating company and OLIS the former agent for British Petroleum in Iceland. They are the main shareholders in CRI from Iceland.

The anticipated test village of 100 leisure houses in NW Iceland. The calculation assumes that each house is 100 m^2. Room heating and ventilation is assumed to be slightly higher than in the other European cases or about 25kWh/m^2 taking into account the sub-arctic conditions. As regards domestic hot water we will assume 30 kWh/m^2/year. This is caused by higher demand in Iceland created by cheap available geothermal water. So hot water demand will be about 5500 kWh on a yearly basis.

Electricity consumption is assumed to be about 2500kWh leading to a total annual energy demand of 8000 kWh per house.

Assuming that the domestic production of methanol in Iceland would lead to prices comparable to world market prices of about 0.45 Euro/litre and that transport to the area in question is possible, the group of 100 houses would have to rely on a methanol cracker of about a third of the size of the Danish scenario which led to methanol cracking equipment amounting to about 1 Meuro.

5. The most relevant stakeholders

The present energy companies in Iceland to participate in the above could be chosen from two types of existing ones: municipal power companies or the oil companies.

It would be expected that power companies like Orkubu Vestfjarda PLC who are current utility deliverers of electricity in NW Iceland would provide the infrastructure for such a programme.

Local heat and electricity engineers in Isafjördur community would be expected to service the system.

The National Energy Authority of Iceland would be expected to provide the legislative environment for the project. At the moment the Authority oversees a subsidy system for "electrical heating of geothermally cold areas in Iceland".

The framework conditions for a test village of 100 households would be set by the National Energy Authority in Iceland.

Figure 3. The NW corner of Iceland, Vestfirdir, relatively cold areas from a geothermal point of view. Source: Ministry of Social Affairs, Iceland

6. Plan for developing the market

The plan for developing the test market in Iceland will have to rely on the availability of methanol from the anticipated FT production facilities. According to the plans of Carbon Recycling International, a fuel production company planned in Iceland, the first methanol could be available around early 2010.

The most likely and feasible path to introduce the concept is through the Federation of House owners in the district.

It would also be feasible to seek financing of the project in cooperation of Ibudalanasjodur, the state run building loan society.

Close linking with the Energy Authority in Iceland with in mind to incorporate the new system into the already existing subsity programme for electricity for heating in geothermally cold areas is a preferred pathway.

7. The actor analysis and possible barriers

As mentioned above, the main actors of the project are likely to be the CRI company and their main cooperators, OLIS fuel company and HS domestic energy company.

One of the most obvious barriers to the project would be the price level of the methanol produced. Among the key ingredients in the methanol production is the hydrogen from electrolysis as has been calculated by CRI.

Hydrogen from electrolysis of water is a feasible possibility in Iceland and we have made assumptions of the price of hydrogen based on the cost of electricity.

A contact has been made to the actors at various stages. First of all the Innovation Center of Iceland is interested in possibly acting as a key organiser of a demonstration project. The Energy Authority has supplied data and the Orkubu Vestfjarda, the local energy company would be interested in participating.

As all depends on the success of CRI, Carbon Recycling International, we have been in close contact with the company and its CEO.

One must realise that the project needs to overcome a number of hindrances before being possible. However, the Innovation Center of Iceland is considering to run an isolated methanol fuel cell system as an opening of this challenging task.

	CRI	Olis and HS	Orkubu Vestfj.	Innovation Center	Energy Authority
Interest	Yes	Yes	Yes	Yes	Yes
Power	Partly	Yes	Yes	No	No
Organisation	Yes	No	Yes	Yes	Partly
Information	Yes	Yes	Yes	Yes	Yes
Access	Yes	Yes	Yes	Yes	Yes
Knowledge	Yes	Yes	Yes	Yes	Yes

Table 1. The table is giving an overview over the main stakeholders and their differing approach and closeness to the project.

In the project the main stakeholders have been contacted and made aware of the options open for the project. The involvement is of course going to vary according to the interests of the involved partners.

The CRI is deeply interested because the project opens up new markets for the fuel anticipated to be produced. The same applies to the Innovation Center where the project is among focal points in energy research. The Energy Authority is also prepared to join the implementation phase which requires a new and fresh look at the existing subsidies for the electricity market in relatively cold geothermal areas.

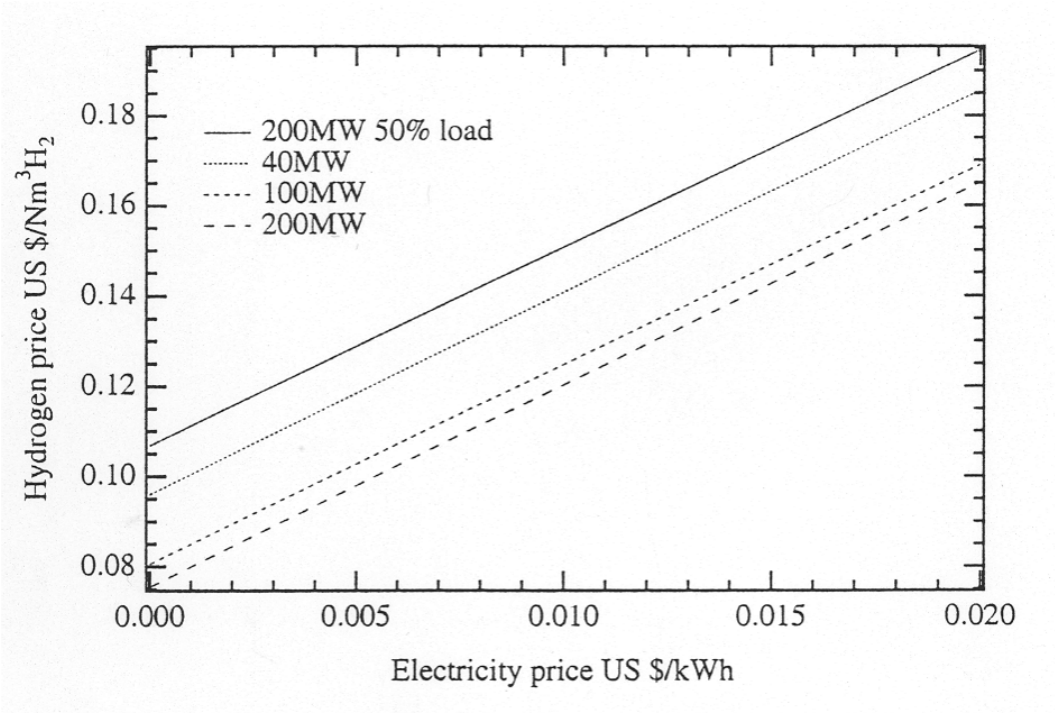


Figure 4. The figure shows the hydrogen production cost based on the Norsk Hydro technology which we have used in a number of calculations for Iceland. The three lowest lines show the production cost as a function of electricity price for plant sizes 40 MW, 100 MW and 200 MW respectively. The uppermost line shows the production cost for a 200 MW plant, which would be in operation at half capacity, for instance 12 hr per day, and thus could eventually be operated on off-peak electricity.

The large scale purchasing of electricity for hydrogen production in Iceland would be possible around 12 Euro mills per kWh in the most favourable cases but environmental concerns have the tendency to push the price range of electricity in Iceland beyond this figure.

8. Conclusion

The present calculation for Iceland contains many factors of uncertainty. However, it provides a very interesting case for testing the use of renewable electricity for producing hydrogen for the production of synthesis gas and methanol suitable for storage and transport as a fuel. In the time span until the anticipated CRI production in Iceland is expected to start in 2009 it would be possible to bridge the time-gap by imported methanol.

WP 3

Regional Market Development Plans

Low cost excess wind electricity / hydrogen in Denmark

Claus Torbensen

Contents

1 Introduction

The purpose of this report is to make a brief description of the relevant regional markets based among others on WP2 and the results of the work done so far. 3 of the 4 planned demonstration projects of FCHS in Denmark are described in the market part of WP2. A short update on where the individual projects are with regards to time horizon and decision making is however needed in order to design the regional MDP.

2 Regional markets in Denmark / Faroe Islands

A. H2PIA

The H2PIA-project is still in a planning/funding phase, and no final decisions have been made in regards to which type of fuel cells to use in the different parts of the project. If sufficient funding is attained the project consisting of 200 households will most likely materialize in 2010-12. The houses are planned to be passive houses; which means that the houses are designed to have a maximum annual heat consumption of 15 kWh/m^2.

B. New project

A newly established project in Herning consisting of 16 household units (4 small apartments in each) is to be built in the fall of 2007. The households are to be powered and heated by high temperature (HT) PEM FCHS (½ kWe + ½ kW heat in each unit). The supplier of the FCHS has been chosen. The hydrogen to be used in the fuel cells will be produced by electrolysis. The system will be connected directly to the electricity grid. The plan is for the electrolyser to run in the period 21-06, and in this period electricity consumption in the households is to be drawn directly from the grid. The rest of the day the fuel cells will be running according to heat requirement/possibility of heat storage of the individual household.The system will be supplemented with an electric heat boiler, that can be utilized in periods with unusually high hot water demand or CHP failure. Periodic excess electricity will be sold back into the grid.

C. Nakskov/Sønderborg

The Nakskov/Sønderborg project will consist of 100 households (phase 3). The project is testing 4 different FCHS technologies: low temperature PEM FC units fuelled with pure hydrogen; HT-PEMFC units with reformer, SOFC units with catalytic partial oxidation and SOFC units with reformer. Phase 3 is planned to commence in 2009/2010.

D. Nolsoy

The Nolsoy project on the Faroe Islands is a 100 % renewable energy project based on wind power (with backup diesel generators). The island consists of 105 households plus a school, industry facilities, a nursery etc. The project is still in an early development phase. The organization behind the project – the Faroese Earth and Energy Directorate is currently working on establishing a consortium to carry out the project, as well as discussing whether to work with micro CHP's or central heat/electricity production.

3 Focus of the market development plans

The following description of the market development plans for Denmark regarding wind and RES FCHS will focus on systems that are plugged into the existing electricity grid – and not directly to a wind turbine. The electrolyser as well as the individual households will be connected directly to the electricity grid

This is the case due to following arguments:

- The electricity generated by wind turbines is already an integrated part of the current market for electricity in Denmark, and the price of electricity in the market is already

affected by the relative high proportion of wind power in the system (the market price is significantly lower than in a system without wind power)[5].

- The cost of wind energy is strongly affected by average wind speed and the size of the wind farm. Therefore the most economical solution, in most parts of the country, will most likely be to establish larger wind farms in the windy coastal areas or at sea, and not necessarily in direct connection to the communities that are to use the electricity in electrolysers and subsequently in the FCHS[6].

- The problems regarding storage capacity and time estimation due to possible absence of wind in longer periods is thus eliminated

A grid connected FCHS-system will basically work as follows:

1. The system will purchase electricity, run the electrolyser and store energy in the form of hydrogen, when the electricity is cheap. This will primarily occur at night and possibly when it is very windy.

2. When the price of electricity is high, the hydrogen will be lead to the fuel cell and produce heat and electricity for the household. Excess electricity will be sold to the grid.

The planned demonstration markets in Denmark that will operate on these terms include the new Herning project and a part of the planned houses in H2PIA.

4 The performance of the energy system

As mentioned in part 3 the price of electricity in Denmark is already affected by the relative high proportion of windmills in the energy supply. As it can be seen in Figure 1 the electricity production from wind mills turbines in approximately 5 % of the year covers the entire electricity demand in West Denmark. In shorter periods the wind turbine electricity production even exceeds demand.

[5] *Vindkraftens betydning for elprisen i Danmark* by Svend W. Enevoldsen, Poul Alberg Østergaard, Poul Erik Morthorst, and Rune Moesgaard
[6] Figure 2 s. 50 wp2

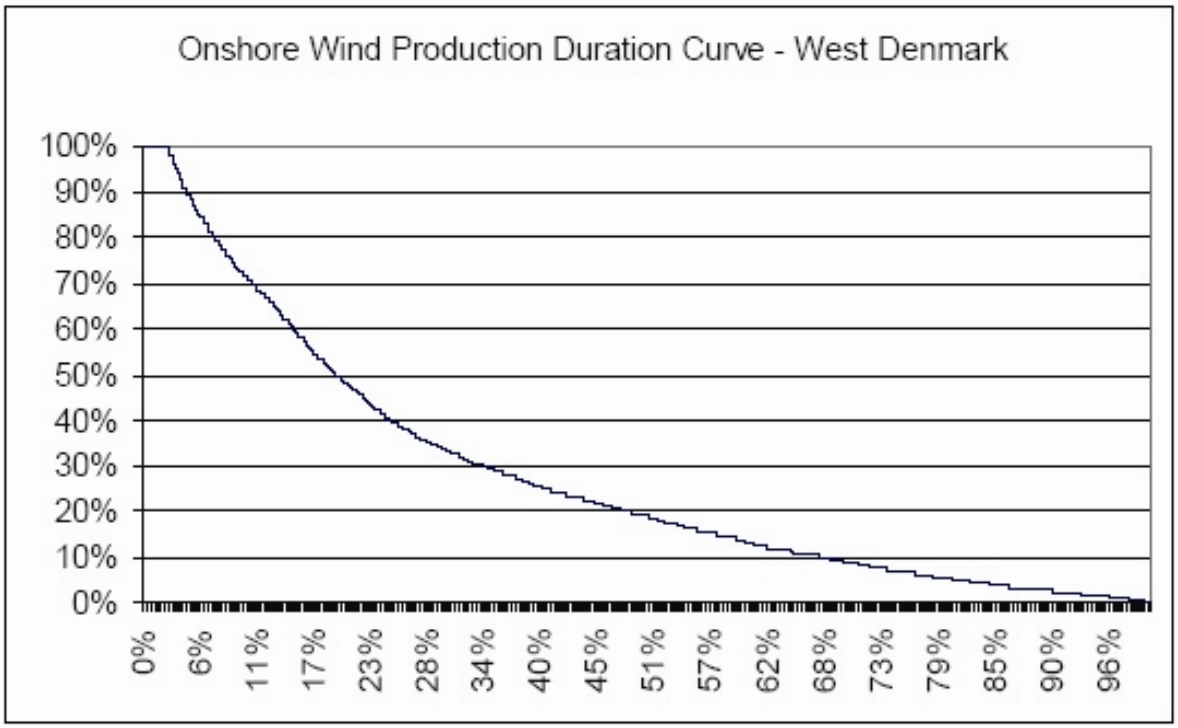


Figure 1: Onshore Wind Production Curve – West Denmark

In the periods where the production in West Denmark exceeds local demand the electricity is sold to Germany, Norway or Sweden through the interconnections. As it can be seen in figure 2 – the price fluctuations are quite large. These fluctuations are partly caused by the relative high proportion of wind power in the energy supply, and create the technical framework conditions within which it makes sense to experiment with electrolysis, hydrogen storage facilities and micro CHP's.

The price variations we see in the market today, are not large enough to secure that a FCHS can operate in a commercial market without feed in tariffs or subsidies (even without taking into account the extra investment in electrolyser, storage facilities etc. compared to conventional means of heat production) due to the conversion losses when going from electricity to hydrogen and back to electricity and heat.

However, this might change in the future as the technologies mature and the transformation losses are likely to be minimized. Furthermore, the proportion of wind power in the Danish energy system is planned to increase significantly in the years to come. A further increase in the proportion of wind mills in the energy supply will all else alike cause the price variations to increase, which can make RES FCHS a economically feasible means of grid balancing in the future.

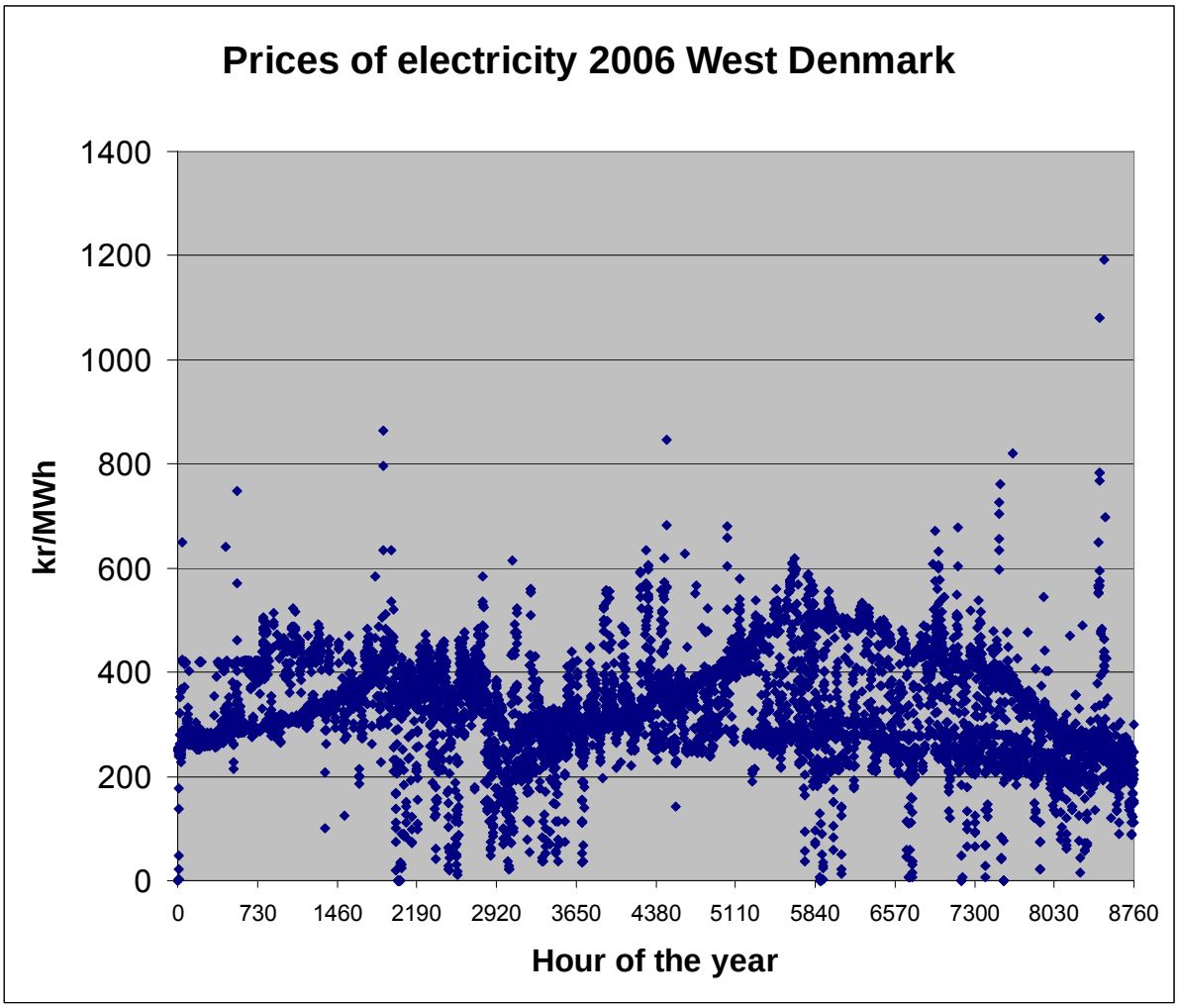


Figure 2: Prices of electricity 2006 West Denmark. Source: BIC

5 The appropriateness of the fuel in question

With regards to production, storage, transport from the storage to the FCHS and safety, pure hydrogen is definitely an appropriate fuel. Hydrogen produced by electrolysis is a most promising method of electricity storage – and electricity storage opportunities are highly necessary if Denmark as mentioned in part 4 is to expand the proportion of RES in the electricity supply.

6 Brief description of the framework conditions and barriers based on WP2

In Denmark there is definitely a future market potential for RES FCHS. A relative large proportion of the Danish households is not connected to central heating sources, and is thus depending on individual applications for household heating purposes. This market is highly relevant for FCHS.

Furthermore, the market price of electricity varies quite a lot – a variation that partly is caused by the relative high proportion of windmills in the Danish electricity supply. If Denmark is to further increase the dependency of wind power in the future, some sort of electricity storage option is required in order to balance the grid. A part of the solution to this problem is to establish electrolyser plants, hydrogen storage facilities and FCHS.

If this scenario is to materialize, it is of vital importance that FCHS become economically competitive to conventional heating technologies. This implies that technological develop-

ments and cost reductions of system components are required (which this project and the demonstration markets is all about).

However, in Denmark there is a strong need for public regulations on RES-FCHS – especially with regards to taxation/tariff issues. The current Danish electricity market and legislation are not yet developed with handling of electricity storage facilities in mind – meaning that it has to be investigated and worked out how a FCHS can operate within the existing energy and electricity legislation.

Investigating and establishing the framework conditions, with regards to legislation, taxation, tariffs and subsidies, is considered the most vital non technical barrier for the creation of a RES FCHS market.

7 Stakeholder Analysis

7.1 Identification of relevant stakeholders

In order to identify all the relevant stakeholders of a RES FCHS system based on hydrogen production via wind power and electrolysis the entire chain from purchase of wind turbine electricity to the selling of surplus electricity will be described.

Energy supply

When purchasing electricity for the electrolyser we can choose from a great number of suppliers on the Danish liberalized electricity market. Some suppliers deal with wind turbine electricity e.g. DONG with their product “naturstrøm” and Nordjyske Elhandel with “grøn strøm”. These products can be purchased at marketprice plus kr. 0,0375/kWh ex vat. There are no barriers or potential problems with regards to electricity supply for the electrolyser.

Energy transformation

The potential suppliers of electrolyser systems are described in WP4. There are several potential owners of electrolyser plants. They can be owned by an association of house owners or a housing association having chosen to implement FCHS’s. In this scenario the association can in some cases have an interest in owning and managing the entire FCHSs. More likely owners are the electricity retailers.

No matter who has the formal ownership of the electrolyser it makes sense if the operational management of the electrolyser and maybe also of the individual FCHS is to be conducted directly (remotely controlled) by a balance responsible player or indirectly by him via a retailer or a broker. This is the case because it requires a minimum capacity of 10 MW to operate directly in the Scandinavian market for power regulation. These 10 MW doesn’t have to be located in one single facility or owned by one entity but has to be controlled by one entity. If the electrolyser reports in on the Spot market on a daily basis, then it will be obvious to also operate at the market for regulating power and thereby increasing the operational income of the system.

The FCHS will in a normal operation cycle act as a means of balancing the grid by purchasing electricity and running the electrolyser at night and running the fuel cells (regulated after heat requirement/possibility of heat storage) during the day. It shall be mentioned that the operation cycle will vary from day to day due to variations in the proportion of wind electricity in the system - as well as the timing of the actual proportion of wind electricity in the system as opposed to what was expected and therefore included in the spot market price setting.

This setup suggests that in a “normal” operation cycle we can:

- Offer up regulation at night by turning off the electrolyser (and possibly run the fuel cells)
- Offer down regulation during the day by turning on the electrolyser and close down the fuel cells.

Energy end-use
The buyers of electricity and heat from this system are private consumers in their individual households. It is likely that a small fraction of the Danish population is willing to pay a small premium on top of their current electricity bill to support green energy technologies. However, this premium is not likely to be very high and if RES FCHS are to be implemented in Denmark in a larger scale and a real market is to be developed, it is vital that the systems become cost competitive for the end consumer. Paying a premium would furthermore be against the "polluter pays principle"

Energy buyers
The network utility supplying the individual household with electricity is also an obvious buyer of periodic surplus electricity produced by the household. The obvious way to settle the account for power bought and sold by the individual household with the network utility is to use the arrangement developed for solar power to settle the accounts for micro CHP's. The owner of a household solar power system in Denmark is settling his account with the network utility on a net consumption basis – meaning that surplus production is send back into the grid and the electric meter is running backwards. Under this arrangement it is of course possible to have a net export of electricity from the consumer/producer to the grid– a net export will however not be settled under the Danish scheme. This is not a problem for solar power since the marginal costs for production is 0 – but for a FCHS where one has to pay for the hydrogen it means that the entire FCHS and the operational strategy has to be dimensioned and operated with the aim of a net export of 0 if the Danish scheme is applied.

Danish ancillary service buyers
The TSO Energinet.dk and the balance responsible players have a clear interest in establishing a more flexible electricity production/consumption. Besides being able to operate on the market for power regulation the electrolyser can provide voltage and frequency regulation to the grid which is definitely an important issue for Energinet.dk

In a future Danish energy supply based on a substantially higher proportion of wind electricity and other RES in the system than today, the main challenge for energinet.dk and the balance responsible players is to develop systems to optimize the use of the regulating power reserve in the decentralized CHP's (including RES FCHS) through development of (remotely controlled) virtual power plants and power pools.

Energinet.dk is at the moment, among other grid balancing measures, looking into the possibilities of electricity storage using hydrogen. They support several hydrogen and fuel cell projects via the Public Service Obligations fund (PSO) which is a fund Energinet.dk administers (all electricity consumers pay a proportion of their electricity bill to the PSO). A part of this fund: "the ForskEL programme" is dedicated to supporting environmentally friendly technologies. Energinet.dk is also represented in several advisory boards and councils working for the advancement of hydrogen technologies. Energinet.dk is an important stakeholder when talking about wind electricity and hydrogen.

Potential users of other by products
The oxygen evolving from the electrolyser process can be collected and sold. However, it is not an economical solution unless the oxygen can be used very close to the electrolyses plant. The possible buyers/users of oxygen are fresh water fish farming facilities and waste

water treatment plants which pump atmospheric air in the water in order to oxidise the water and thus decompose organic matter. These facilities can if they choose to pump pure oxygen in the water instead save a large fraction of the energy used to run the pumps as the concentration of oxygen is five times that of atmospheric air. The market value of the oxygen will thus be close to the value of the energy saved. An estimate is that the value of the oxygen is approximately 0,07 Euro/Nm3. This is not a substantial amount and the setup can therefore only carry a minimum of distribution costs.

Authorities setting framework conditions

The Danish Ministry of Energy and Transport.

In the Danish government's latest energy political draft of the 19th of January the Minister of transport and energy, Flemming Hansen, announced that the government wishes to offer the optimal conditions for research and testing of new and promising energy technologies. The government furthermore wishes to spend an increased amount of money to support development and demonstration of new energy technologies in the years to come – including hydrogen technologies. They have allocated Euro 6,7 mio. to a demonstration project in 2007 of FCHS, and they also want to exempt hydrogen powered cars from taxation. These actions indicate that the Danish government is sticking to the strategy formulation, regarding research, development and demonstration of hydrogen technologies, published by the Danish Energy Authority (DEA) in June 2005. In this paper it is pointed out that it is essential to provide the legal framework conditions (including subsidies and tariff reductions) within which it will be possible to develop a market for hydrogen technologies (including FCHS). Since such legal measures will have to be approved at a political level the ministry and the Danish parliament are of course the most vital stakeholder. However concrete initiatives with regards to management and how to frame new legislation will probably to a large extent involve The Danish Energy Authority.

The Danish Energy Authority

It is the task of the Danish Energy Authority to advise the minister, to assist other authorities, to administer Danish energy legislation and to conduct analysis and assessments of the development in the field of energy, nationally and internationally.

The Danish Energy Authority carries out tasks, nationally and internationally, in relation to the production, supply and consumption of energy. This means that the authority is responsible for the whole chain of tasks linked to the production of energy and its transportation through pipelines to the stage where heat, electricity etc. are utilised for energy services by the consumer.

By establishing the correct framework and instruments in the field of energy, it is the task of the Danish Energy Authority to ensure security of supply and the responsible development of energy in Denmark from the perspectives of the economy, the environment and security.

Energy research and development

In order to limit the long-term energy costs of society and, not least, of enterprises and to safeguard future security of supply, it is an area of constant focus for The Danish Energy Authority that new and more energy-efficient technology is constantly developed.

The Danish Energy Authority administers the Energy Research Programme (ERP and EUDP), which grants subsidies to R&D in the area of cleaner and more energy efficient technologies.

The Danish Energy Authority has a strategy for hydrogen and fuel cells aiming at increasing Danish R&D efforts and demonstration projects in the area of hydrogen and fuel cells. The formulated strategy and the organisation created with the intent of implementing the strategy is the forum within which the Danish Market Development Plan with regards to wind electricity and FCHS is being developed.

7.2 Stakeholder analysis

Only a few of the identified potential stakeholders are relevant to describe further at present time, due to the fact that the market and the planned demonstration projects are not far enough in their development and the framework conditions required are not yet established or the needs fully understood - making it to early to include some of the potential actors in a description of MDP.

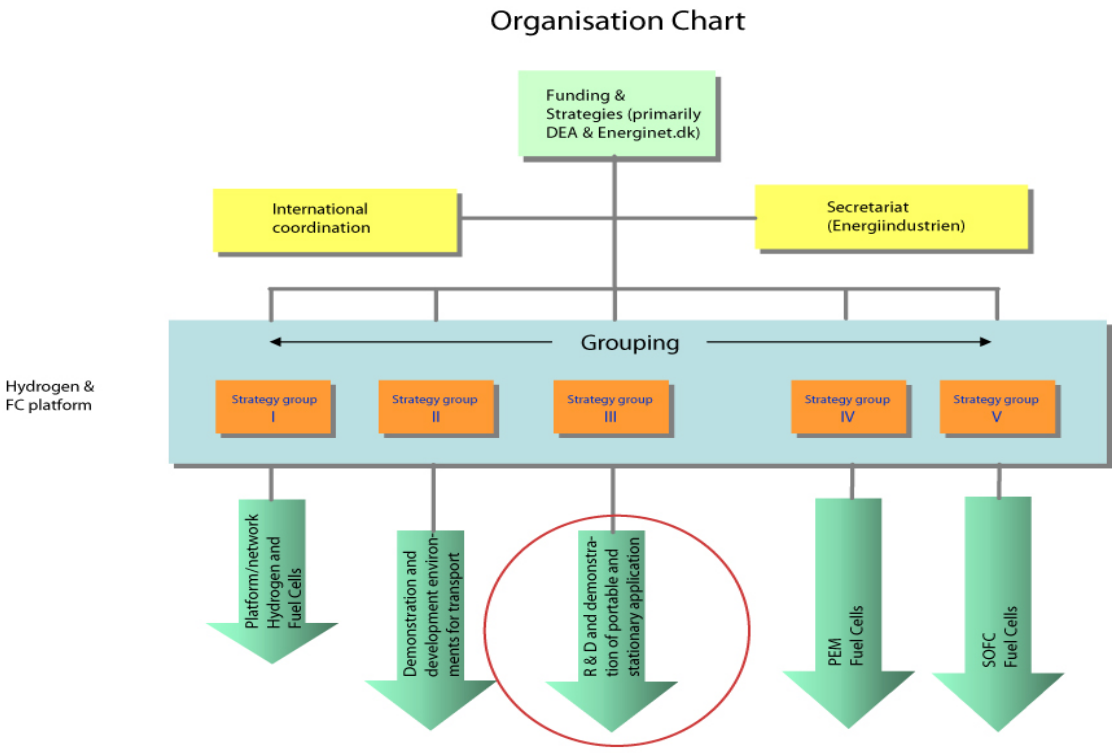
These actors, however shall, and is to be included in the planned demonstration projects where more concrete work and experimentation are to be performed.

Table 1: Overview of the actors

	Danish Ministry of Energy and Transport	Danish Energy Authority (DEA)	Energinet.dk
Interest	Yes	Yes	Yes
Power	Yes	Work within the political agenda	Work within the political agenda
Organisation	Yes	Yes	Yes
Information	Coming from DEA	Yes	Yes
Access	Yes	Yes	Yes
Knowledge	Yes	Yes	Yes

The key technology carriers are DEA and Energinet.dk since they are in charge of or deeply involved in funding of demonstration projects in the area of hydrogen and fuel cells. Both entities are continuously working with strategy development in cooperation with representatives from research institutes, industry, universities etc.

This work is among other places being performed in various councils and advisory boards, with one of the most important one being the Danish Platform for Hydrogen and Fuel cells. This organisation is relatively new and is planned to be heavily involved in the implementation of the Danish strategy for hydrogen and fuel cells. The organisation chart can be viewed in Figure 3.



Figur 3. Danish platform for hydrogen and fuel cells

The partnership is coordinated and managed by Energiindustrien, and has a specific strategy group (group 3) working with demonstration and development environments for stationary and portable applications (including RES FCHS).

<u>Members of strategy group 3</u>

Danfoss Director	Fuel Cell Business, Per Balslev
Dantherm	Manager, Jesper Themsen
HIRC	Technical Manager, Lars Yde
IRD a/s	Manager Jørgen Lundsgaard
Nakskov Kommune	Business Development Manager, Leo Christensen
Topsoe Fuel Cell	Director, Business Development, Helge Holm-Larsen
Energinet.dk	Programme Coordinator, Inger Pihl Byriel
Energinet.dk	Fritz Luxhøj,
DEA (Chairman)	Programme Manager, Aksel Mortensgard
Energiindustrien	Consultant René, Kaalø Rothmann

A former working group managed by DEA did the work and the analysis forming the basis for DEA's and subsequently the Danish MDP strategy for hydrogen and fuel cells. The plan is for the strategy groups under Energindustrien to be responsible for the further strategic development in the area, as well as they are to evaluate the contingency between the R&D efforts in the area and the technical targets formulated for the development.

The strategy and the targets set for development include wind power and FCHS. The plan addresses and acknowledges the perspectives for storing cheap electricity in hydrogen via electrolyses, and using the energy in various applications including micro CHPSs. The specific recommendations/goals formulated by the DEA working group relevant for small FCHS are as follows:

Short term (0-5 years)

- Internationally competitive economic public support to demonstration and market development of systems up to 25 kW_e primarily based on RES fuels but also temporarily for fossil fuels.
- Introduction of subsidies (tariffs/feed in tariffs and environmental regulation) to overcome barriers for the introduction of hydrogen technologies.
- Pull products to the market by increased cooperation between Danish technology providers, the energy sector and private consumers through a series of demonstration projects.
- R&D and demonstration of storage and production of hydrogen and hydrogen carriers primarily based on RES.
- Decentralized plants shall be actively incorporated in the electricity grid.
- Establishment of common conditions for decentralized plants building on various technologies

Medium term (5-15 years):

- Public support to the development of hydrogen technologies in the industry and electricity sector.
- Completion of larger demonstration projects including a large number of end consumers including active control (power pools or the like)
- Subsidies to installation and use of systems based upon RES fuels.

Long term (15-25 years):

- Demonstration of pure hydrogen based solutions in a larger scale including a partly developed hydrogen infrastructure.
- Continued but decreasing support to installation and use of systems in Denmark to secure a continued development of the market.
- Support for further development and optimizing.

This is an overall plan with a goal of establishing the framework conditions, necessary for developing the Danish market for wind based FCHS. The plan 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 point: Establishment of common conditions for decentralized plants building on various technologies, can however be interpreted as it is hoped to get a similar arrangement for FCHS as it is currently the case for solar power.

The general opinion among a majority the of the contacted members of the strategy group, is that more knowledge and experimentation is required in order to be able to formulate concrete suggestions for framework conditions etc. for the area.

This does not mean that the area is not being looked into. In connection with the Nakskov project lawyers from Danfoss, DONG and DEA are currently investigating how the planned demonstration project can be operated within the current energy legislation. When this is fully investigated it is likely to form a basis for a suggestion for future regulatory planning.

The key element in the Danish MDP is thus to initiate and support demonstration activities, and let the concrete development and suggestions, for future regulatory planning evolve directly or indirectly from the demonstration projects where technology providers, research institutions and network utilities work closely together.

Which body/board or other entity this suggestion is to come from is at the moment difficult to say.

The number of companies, organizations and research institutions working with hydrogen and fuel cells in Denmark is relatively low – meaning that the collaboration on demonstration projects, and the work being done in various councils and advisory boards to a very large extent are done by the same companies and the exact same people “in different combinations”.

However, it is almost certain that the first steps are not to come from DEA, Energinet.dk - or the Platform for Hydrogen and Fuel Cells Partnership (since DEA and Energinet.dk are heavily represented in this forum) because they are obliged to work within the outlined political agenda.

The task for all other stakeholders in the RES FCHS industry is thus to continually inform and put pressure on the politicians in order to make them in favour of establishing the framework conditions necessary for RES FCHS.

Environment, pollution and climate change concerns are issues that concern a lot of Danes. According to a recent survey (Eurobarometer 67) 26% of the Danish population consider environmental problems as one of the two most important issues currently facing our country.

The public opinion is of course of major importance to the politicians – and therefore it is also of vital importance to be very visible in the media and continually inform about the potential lying within hydrogen technologies. This information activity is, and is to be performed individually by all stakeholders in the sector, as well as by the different fora where the various stakeholders cooperate.

The Danish Hydrogen Association (DHA) is an important one of these fora. The organisation consist of members from the entire value chain – from basic research institutions to companies working with storage, distribution and pre-commercial/commercial products. DHA can very well be the forum from which concrete suggestions for improved framework conditions and legislation are to come. The area is actually mentioned in DHA’s objects clause – but as of now no concrete work on the matter is being conducted. At the last board meeting, it was suggested by one of the members to start working on framework conditions. The subject was very briefly discussed but no concrete initiatives are planned.

8 Summary

Denmark has an overall strategy for hydrogen and fuel cells. In the strategy it is among other things pointed out that it is important to provide the necessary framework conditions necessary for pulling “hydrogen products” to the market. The plan 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 public opinion in Denmark is increasingly concerned about environmental problems, and this of course puts pressure on the politicians to follow up on their strategy/ “declaration of intent” with more concrete and specific initiatives.

The Danish MDP is quite heavily focused on demonstration projects – funded partly by private companies and public funds – of which some of the most important are administered by DEA and Energinet.dk. 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.

DEA and Energinet.dk are influential stakeholders in this process, but since they are bound by the political agenda, initiatives of suggestions regarding establishing of improved framework conditions are not to come from them – but they will undoubtedly be involved in the process, when and if the politicians decide to take action in the area.

The key element is therefore for all other stakeholders in the industry to keep informing the general public and the politicians about the possibilities lying within RES FCHS, as well as the necessity for legislative measures to support the development of the technologies.

These information efforts are vital – but it will be beneficial to the cause if they are supplemented with concrete suggestions for future RES FCHS legislation. These suggestions can of course come from individual companies or groups working on various demonstration projects – but it would give a proposal more weight if it comes from an organisation representing members from the entire Danish Hydrogen Industry. No board or organisation is currently doing work in this area – but when the demonstration projects are a bit further in their development /materialization someone will have to pick it up. An organization that seem equipped to the task is DHA.

WP 3

Regional Market Development Plans

Excess wind/hydrogen, Netherlands

Gerard J. Kraaij

Contents

1. Regional Market Development Plan excess wind/hydrogen for the Netherlands

1.1. Introduction

In WP2 the characteristics of the market for excess wind/hydrogen for Friesland and the Netherlands are determined. In this workpackage the market development plan is provided. The market development plan describes how the barriers identified in WP2 can be overcome. Barriers exist on different levels. These are specific barriers for the technology and specific barriers of the concept considered for CHP in households. In addition there are other developments that are not really barriers but alternatives that compete with the application considered and may hamper this application.

The following general barriers for the application of hydrogen based fuel cell household systems exist:

1. The cost of fuel cell household systems is still too high for commercial application.
2. The lifetime for fuel cell systems needs to be extended.
3. The regulation for the safety of hydrogen in houses is in development; e.g standard odorants for natural gas are not suited for hydrogen because the low density of hydrogen causes separation of odorant and hydrogen.
4. The public has no experience with hydrogen as an energy carrier.

R&D can alleviate the first 2 barriers on the fuel cells and the fuel cell system in combination with mass production for cost reduction; this last item is addressed in the current project. In the initial stage subsidies can be granted for the extra investment costs. The work on the European wide regulations and legislation for hydrogen and fuel cells in households should lead to regulations that alleviates barrier 3. Dissemination to the public and installation providers is required for alleviating barrier 4 and this is also addressed in this project.

For Friesland and for the Netherlands barriers exist on:

5. There is no excess wind energy available in the Netherlands or Friesland at this moment for providing renewable hydrogen.
6. The subsidy for renewable electricity (MEP) has been stopped in the Netherlands in August 2006 for new projects because the target of 9% renewable electricity in 2010 will be met. This meant that many renewable energy projects were put on hold or stopped. The new subsidy for renewable electricity SDE will start in 2008. In this SDE fuel cells are not mentioned for specific support or subsidy.
7. For application of fuel cells in houses on the scale of a district with a hydrogen grid, it is required that a successful demonstration is shown and it has to be incorporated in the development plan for this district. It lasts about 3 years from development plan to the realisation of the district.

For barrier 5 it is required that at least 6 GW of wind turbines are installed above the present installations, and that it is clear for the investors in wind parks what to do with excess wind electricity. For barrier 6 it is required that the government has a stable and long-term policy on support of renewable energy supply and that the role of fuel cells as a technology for energy conversion is addressed. Barrier 7 requires that the aforementioned barriers are lifted (except 6) and that the technology shows its potential.

Developments and observations that can hamper the market development of “renewable hydrogen” based fuel cell household systems are:

- Competing options to introduce renewable energy in households like photovoltaic systems or solar boilers.

- The competing application for hydrogen in CHP is hydrogen as a clean fuel for transport. In combination with fuel cells this will also have a high efficiency compared to internal combustion engines.
- Alternative energy storage systems for the electricity market with high efficiency like CAES (compressed air energy storage) and pump accumulator are competitors. These systems require specific geological areas.
- Scenario studies like the ones performed by EC (WETO-H_2 "World Energy Technology Outlook 2050"; 2006), IEA ("prospects for Hydrogen and fuel cells"; p.27; 2005) and Hyways do not foresee a significant role for hydrogen based fuel cell household systems.

These 4 barriers/observations require that the fundamental question of the perspective of the technology should first be addressed for the Dutch situation in the light of existing systems and competing options. A market perspective is required before a market development plan is made. The question of market perspective is the subject of the next paragraph.

First the amount of excess electricity is addressed; its conversion to hydrogen and the conversion back from hydrogen to electricity. Two operating strategies are chosen which differ because of the electricity feed-in regulations. The economics of these 2 options are compared to the existing energy prices for households in the Netherlands. The Investment costs for large scale application of fuel cell household systems operating on hydrogen from excess wind electricity are estimated.

In paragraph 3 the regional initiatives are described together with the view of the main stakeholders with respect to the technology and market.

In paragraph 4 the conclusions are presented.

2. Perspective of wind-to-hydrogen fuel cells in the Netherlands

2.1. Introduction

Large scale off-shore wind power can lead to the situation that more electricity is available (including the base load electricity supply) than needed in the Netherlands. The question is if the unbalance in time of electricity supply and demand can be solved cost and energy effective by conversion to and storage of Hydrogen (H_2) together with household micro Combined Heat and Power (micro-CHP) electricity and heat production using Fuel Cells (FC) during periods of electricity shortage of supply. For the Netherlands the case of non-deployable or excess wind to micro-CHP is investigated as shown in Figure 1.

The main assumptions for this part of the study are:

1. Excess (off-shore) wind power converted to hydrogen by electrolysis.
2. Hydrogen used in 1 kW_e micro-CHP FC in households for electricity and heat generation
3. An average Dutch household uses 3500 kWh of electricity/year
4. Micro-CHP unit operated only in non-excess wind power hours (overall efficiency)
5. Micro-CHP unit operated in
    a. electrical load following operation (low feed-in tariff)
    b. feed-in operation where the amount of electricity withdrawn from the grid equals the amount fed into the grid

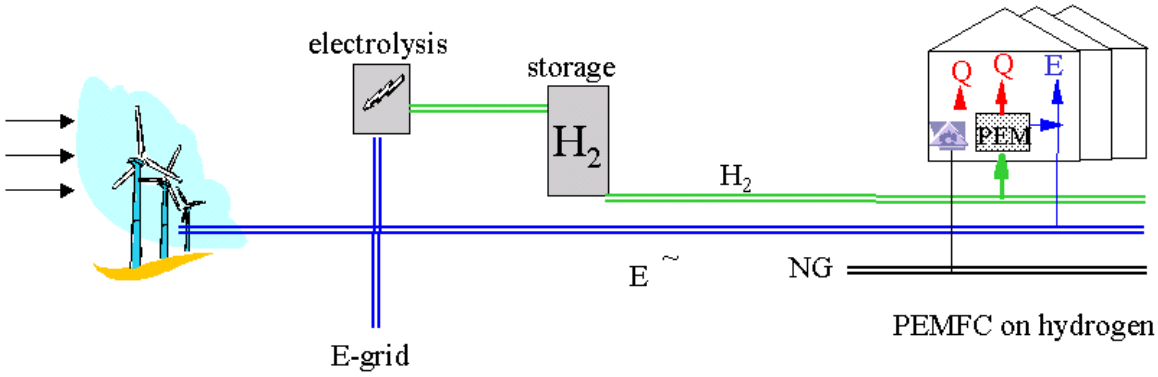


Figure 1: System with excess wind electricity and micro-CHP fuel cells on hydrogen.

2.2 Excess wind power determination

In a study by TenneT [1] the electrical load with and without wind power generation are provided and reproduced in Figure 2. For the determination of the excess wind power a base load electricity generation of 8.7 GW is assumed, corresponding also to the minimum annual load. The area under the blue base load line is denoted as excess wind power. With this assumption the excess wind power for the 8 GW wind power case is 4.9 TWh which is identical to the base case excess wind calculated in the TenneT study. In this TenneT study for 15 min. intervals the measured electricity demand is compared to the calculated the wind energy production from wind speed measurements and the controlled central power plant production for a 1 year period. In the situation that the electricity production is higher than the demand and the central power plant electricity can't be reduced for dynamic reasons, the resulting electricity production is non-deployable or excess wind energy. Electricity export possibilities are not considered.

For this study 10 GW installed wind power is assumed, which means that the 8 GW installed wind power case is extrapolated to a 10 GW electrical load case. This provides more excess wind power and for a larger time period. The excess wind power for 10 GW installed wind power is then estimated as 8.4 TWh. In the TenneT study [1] the way of calculating the excess wind power is different, however it can be expected that the time period for excess power will be similar for the 2 approaches. The investment cost for off-shore wind turbines are 2200 €/kW installed and the off-shore load factor for the Netherlands is 46%.

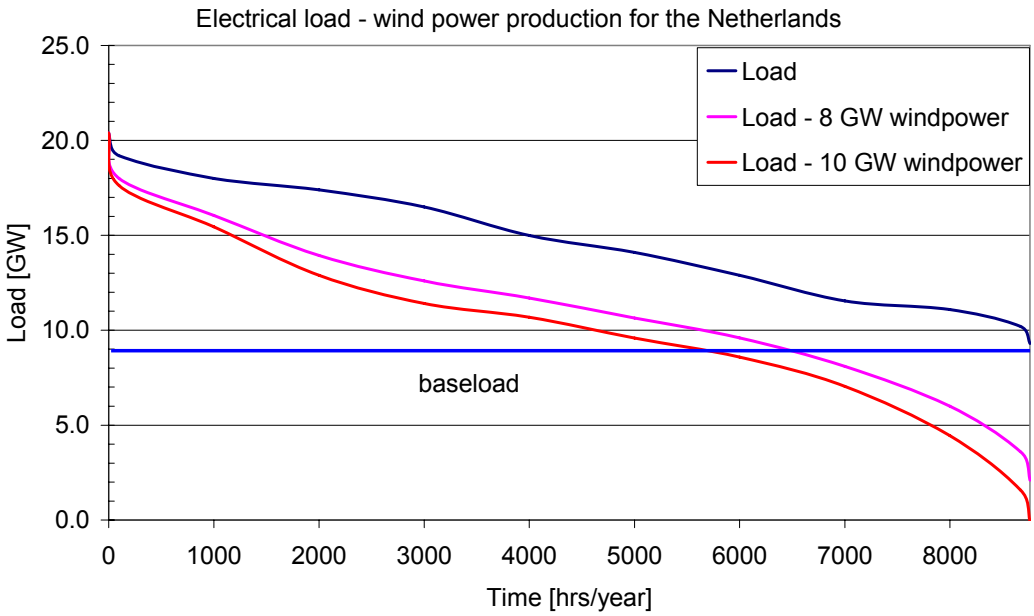


Figure 2: Electrical load for the Netherlands with and without wind power. The line for 10 GW wind power is extrapolated.

2.3 Electrolysis and hydrogen grid

The excess wind power can be converted to hydrogen by electrolysis. The electrolyser efficiency used in this study is 68% on the LHV (lower heating value) basis of hydrogen which is 81% on the HHV (higher heating value) basis and the electrolyser output pressure is 13 bar. Next the hydrogen has to be compressed and stored. It is assumed here that the compressor capacity is equal to the electrolyser capacity and that the output pressure is 60 bar. The hydrogen storage size requirements and associated costs due to the unbalance in hydrogen production and usage are not investigated here.

The hydrogen will be inserted in a hydrogen grid and transported to the houses. The cost for the hydrogen infrastructure is estimated from the present transport and distribution costs for natural gas (1.89 €/GJ). For an average household using 1700 m^3/year natural gas (NG) this amounts to 80 €/year. For the hydrogen grid a double amount of 160 €/year will be assumed since a new grid has to be made with more requirements.

2.4 Micro-CHP fuel cell system electrical load following operation mode

For the micro-CHP fuel cell system a 1 kW_e PEMFC system operating on hydrogen in electrical load following mode is assumed since the feed-in tariff for electricity is only in the order of 0.04 €/kWh (exception see chapter 2.5) in the Netherlands and it is therefore not economical to size the unit for grid delivery. The voltage-current density curve for a PEMFC operating on H_2 of Figure 3 is used. For the analysis of the micro-CHP system in this report the current density is arbitrary, for the 1 kW_e operating point a mean cell voltage of 650 mV_{dc} is assumed.

Thermal and electrical losses for the system are assumed, leading to the electrical and thermal efficiencies depicted in Figure 4.

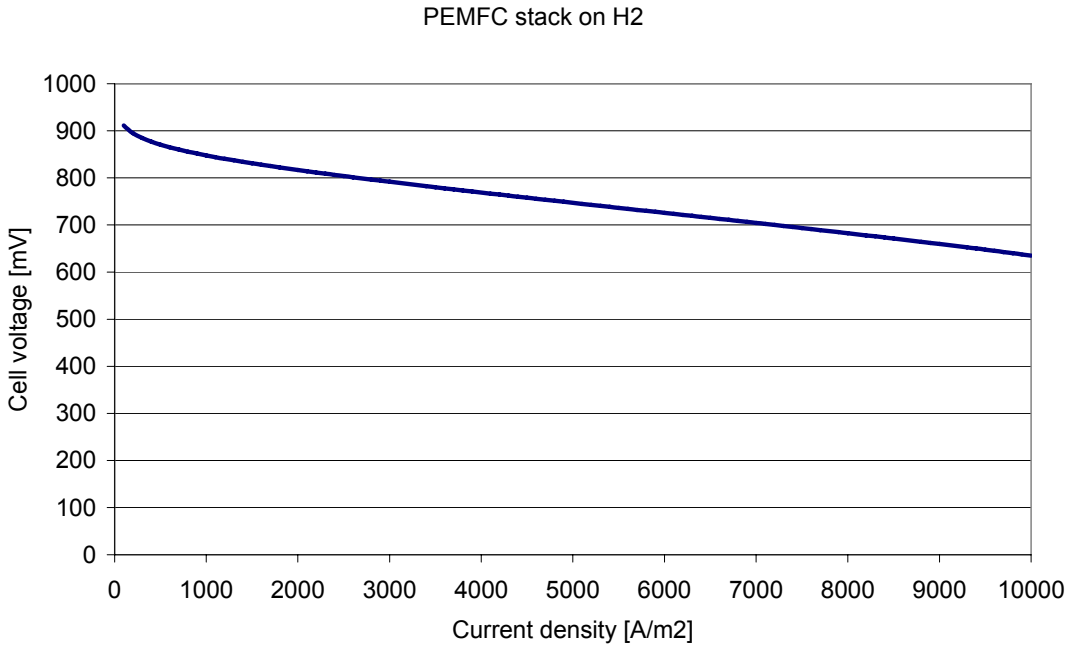


Figure 3: Voltage-current density curve for a PEMFC on hydrogen used for modelling.

The maximum total efficiency at 1 kW_e is set to 90%, a value that can be found also in literature for these small systems [2]. From Figure 4 can be seen that the total efficiency reduces at part load due to the power independent losses in the system.

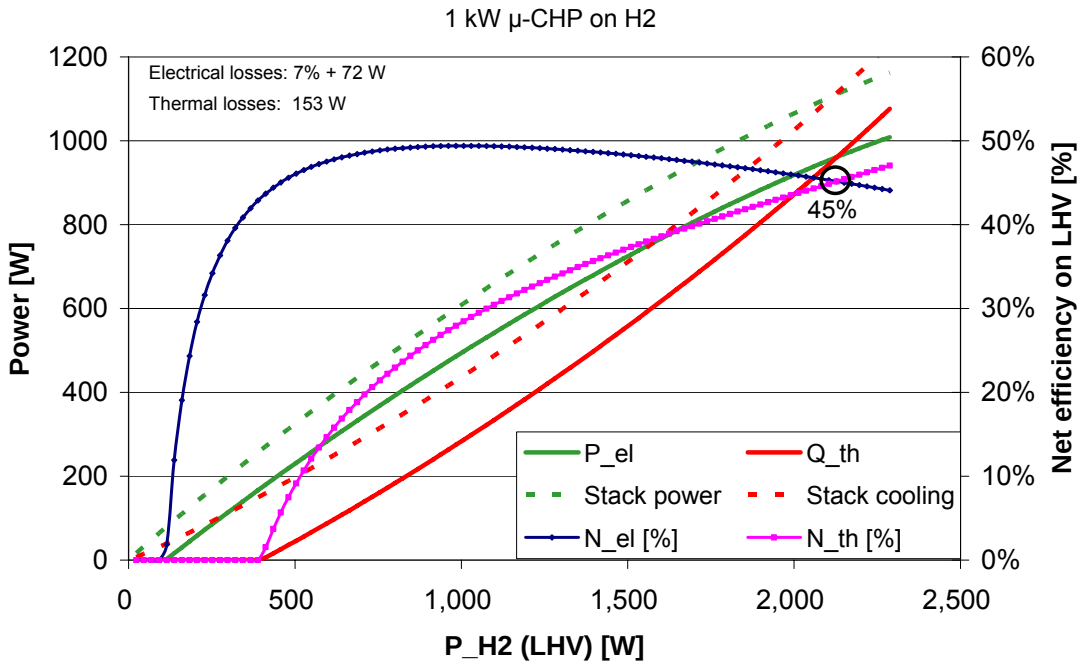


Figure 4: Net electrical (P_el) and thermal (Q_th) output of a 1 kWe micro-CHP PEMFC system, gross stack output and net resulting efficiencies as a function of the HYDROGEN power input in LHV.

In the electrical load following operation in a household, the micro-CHP system can provide a part of the electrical load, as can be seen in Figure 5. An average household electrical load of 3500 kWh is used, together with a measured daily load profile.

In the arrangement according to Figure 5, the micro-CHP unit can provide 81 % of the load. 12% of the load can't be provided since the load is larger than 1 kW_e, 7% can't be provided since the load is loo low and the system will be shut-down for technical as well as economical (efficiency) reasons. Here it is assumed that the system operates between 20% and 100% electrical power.

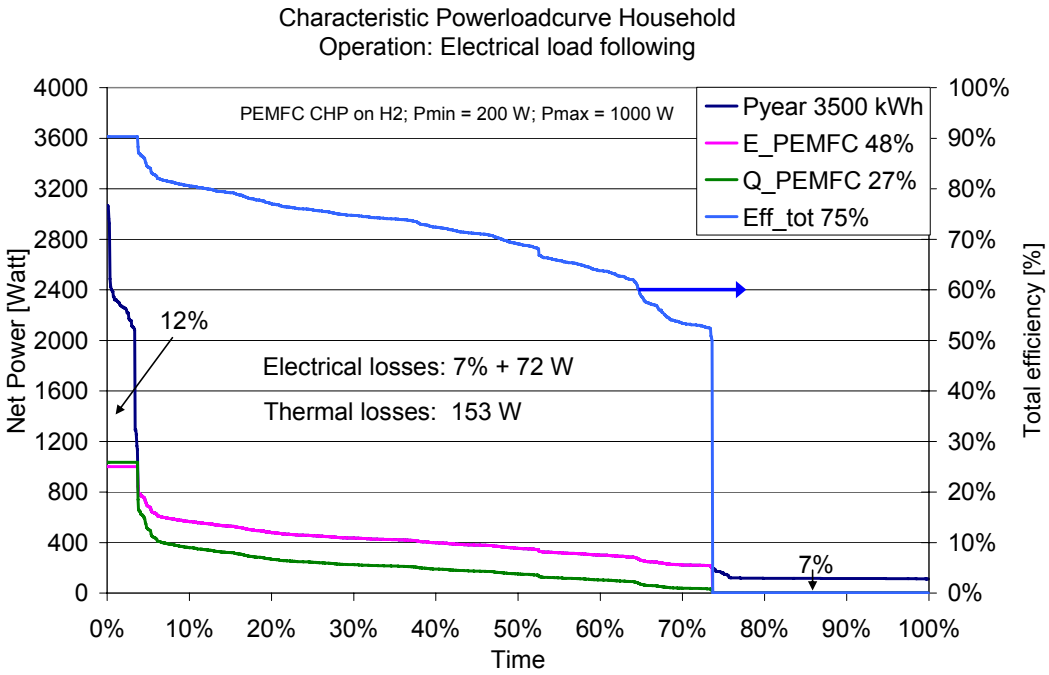


Figure 5: Characteristic electrical load following operation for average household.

The electrical load following operation is also the reason that the system operates most of the time in part load. The mean overall efficiency for the average household is calculated as 75%, of which 48% is electrical and 27% thermal. . The tap water will be heated using a heat exchanger with the cooling system for the PEM fuel cell. The useful heat from the fuel cell system is approximately 1400 kWh, which is 40% of the energy need for tap water. With sufficiently sized hot water storage system, the heat of the fuel cell can be accommodated. This means that also other heat supply is needed for the household. The temperature of maximum 60°C of the hot water from the PEM fuel cell system is also low and requires extra heating before it can be used for tap water

2.5 Micro-CHP fuel cell system feed-in operation mode

Taking into account the present day Dutch feed-in tariff regulation for renewable energy (based on PV systems) which is equal to the consumer price (0.218 €/kWh in 2007) as long as the amount of feed-in does not exceed the amount of electricity withdrawn from the grid at another moment, but with a limit of 3000 kWh.

In all other cases the Dutch feed-in tariff is approx. 0.03-0.04 €/kWh. Then the optimal operating strategy for the fuel cell system would be maximum power during non-excess wind hours and in total providing the yearly domestic electricity demand as shown in Figure 6. The average heat from the fuel cell system now compares well to the average tap water needs.

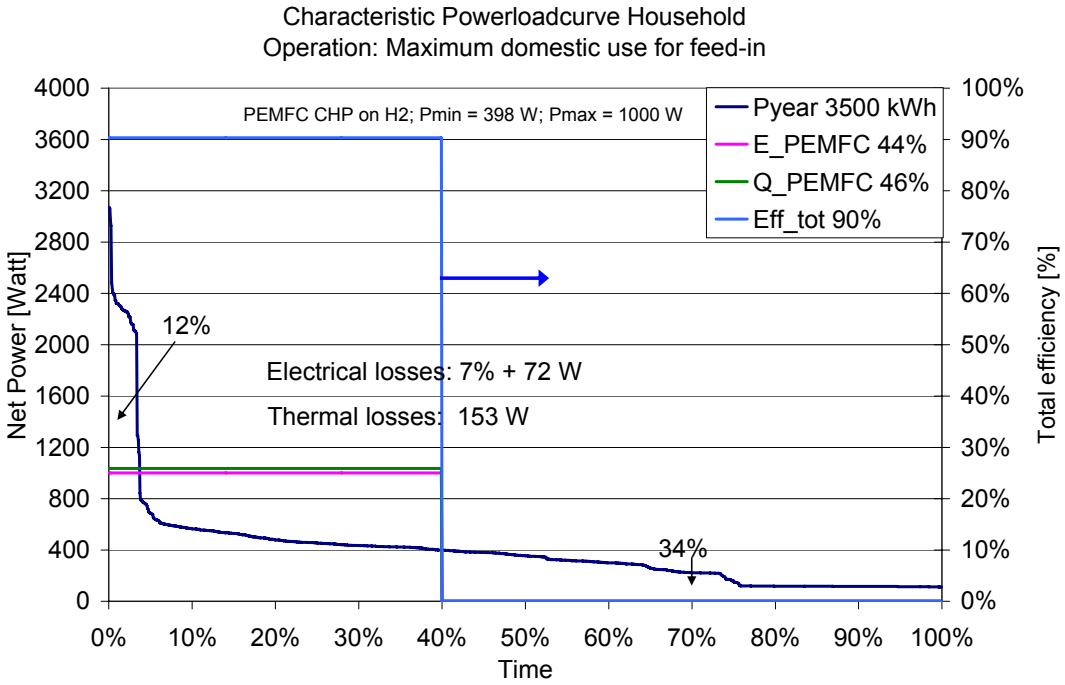


Figure 6: Optimal FC operating strategy for present day feed-in arrangement

2.6 Excess wind power and micro-CHP

For the micro-CHP system operating on hydrogen coming from excess wind power electrolysis it is assumed that it only operates when there is no excess wind power and that the control signal for this is provided through the grid. In this way it is prevented that the micro-CHP unit makes extra power when there is already excess electricity. The operation time of the micro-CHP system in combination with the 10 GW installed wind power capacity is shown in Figure 7. The 8.4 TWh excess wind energy is converted to 2.6 TWh of useful electrical energy and 1.5 TWh of useful heat.

In the electrolyser 19% of the energy (1.6 TWh) is converted to heat at 80°C. In this case the maximum cooling requirement is approx. 1.3 GW for 7 GW installed electrolyser capacity, which is 2-3 times more than needed for present day single power plants. These power plants, located at riversides, occasionally have problems with cooling water capacity. The maximum purified water usage for the electrolyser process is 1300 m^3/hr. These items are outside the scope of this study and will require further investigation.

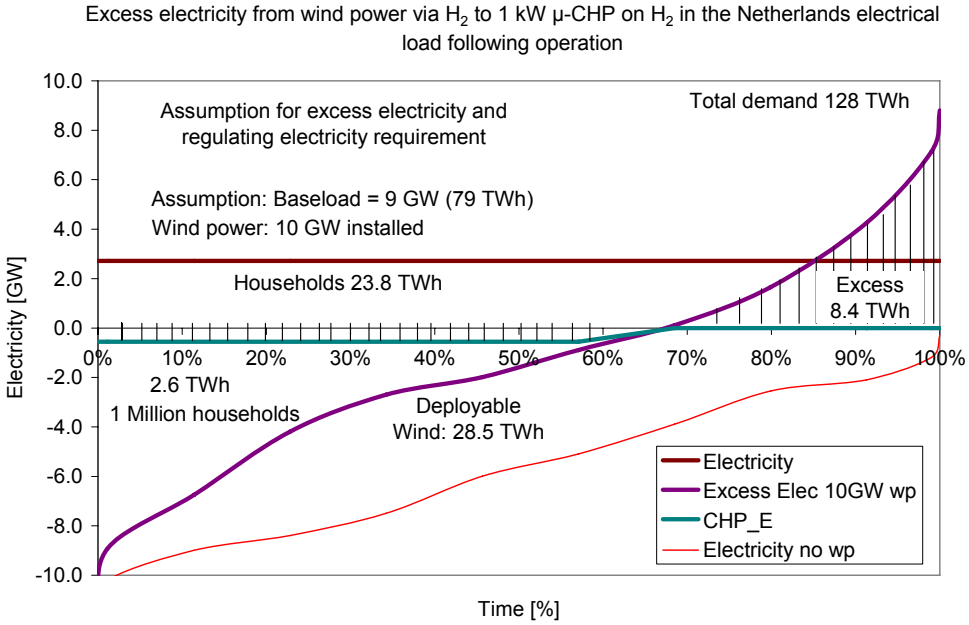


Figure 7: Excess wind power and micro-CHP operation at 10 GW installed wind power case.

2.7 Cost of electricity

The cost of the electricity produced by the micro-CHP household system depends mainly on the investment costs for electrolysers, HYDROGEN infrastructure and the fuel cell system, the efficiency of the process, the time of excess wind energy and the cost of the excess electricity.

The assumptions made on the future investment costs, efficiency etc. are:

- Electrolyser cost is 500 €/kW$_e$ (target HYSTRUC project; DoE target = 300 $/kW$_e$)
- Fuel cell system cost is 1000 €/kW$_e$ [5].
- Hydrogen grid cost is 160 €/household/year = 0.06 €/kWh$_e$/year
- The round-trip efficiency of the process is 31% electrical and 17% thermal
- The cost of excess electricity is set to 0.02 €/kWh$_e$ or 5.56 €/GJ. This is the minimum spot market price for electrical energy in the Netherlands and comparable to the price of natural gas for very large consumers, based on the same energy content. Transportation costs and taxes are neglected.
- The value of the useful heat from the fuel cell system is equal to the consumer unit energy price for natural gas (0.59 €/m^3 = 0.067 €/kWh$_{th}$). All heat can be used.
- Interest rate of 5% and component specific technical lifetime assumptions (10-30 years).
- The time of excess wind energy is 33 % in the 10 GW installed wind power case, which corresponds to approx. 17% full load operation of the electrolyser.

The price structure and efficiency along the process steps is given in Figure 8 without profit or taxes for the electrical load following operation of the fuel cell system. The process step "fuel cell heat" shows the effect of the use of the heat from the fuel cell on cost and total efficiency. In this case the cost of electricity of 0.31 €/kWh$_e$ is already higher than the present consumer price for electricity including taxes, profit etc. Moreover, the cost of electricity from the fuel cell is 0.03€/kWh$_e$ higher for every increase of 0.01 €/kWh$_e$ for the cost of excess electricity due to the efficiency loss. The average cost of off-shore wind electricity for the Netherlands will be approximately 0.07 €/kWh$_e$ and this value should be used when wind

parks are specifically build for hydrogen production. This leads to a cost of electricity of 0.46 €/kWh$_e$

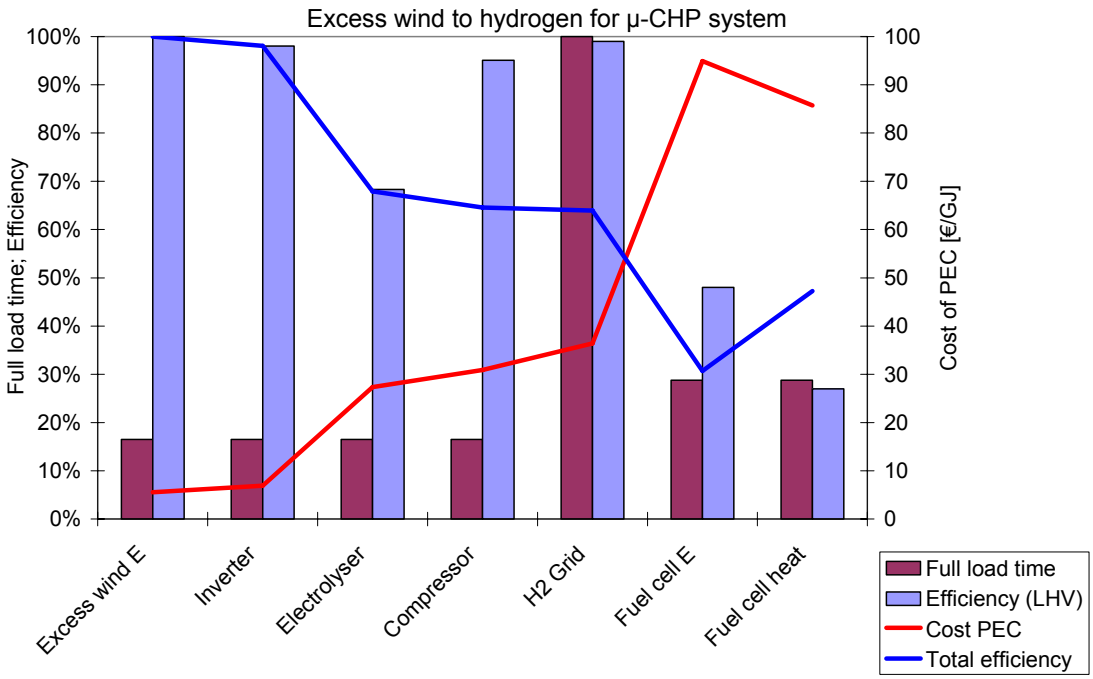


Figure 8: Efficiency and cost at the different process steps for the 10 GW wind power case. PEC = primary energy carrier (either electricity or hydrogen)

In Figure 9 the time of excess wind energy is varied between 10 and 90%. The minimum cost of electricity is calculated at an excess wind energy part for about 50% of the time. At the left part of Figure 9 the CoE is high because the electrolyser operating time is low and at the right side the CoE is high because the fuel cell operating time is low since it will only operate during non-excess wind hours. In Figure 10 the minimum cost of electricity is calculated for the economic optimal operating strategy for the fuel cell system from Figure 6. In this case the minimum cost of electricity is lower. In Figure 9 and Figure 10 also estimations are provided for the amount of installed off-shore wind power that is needed for reaching a certain excess wind energy operating time using an extrapolation of Figure 2.

The main investment costs for the 10 GW installed wind power case are estimated as:

Inverter (7GW)	300 M€
Electrolyser (7 GW)	3500 M€
Compressor	300 M€
HYDROGEN infrastructure	1600 M€
Fuel cell systems (1.2 Million)	1200 M€
Total	6900 M€

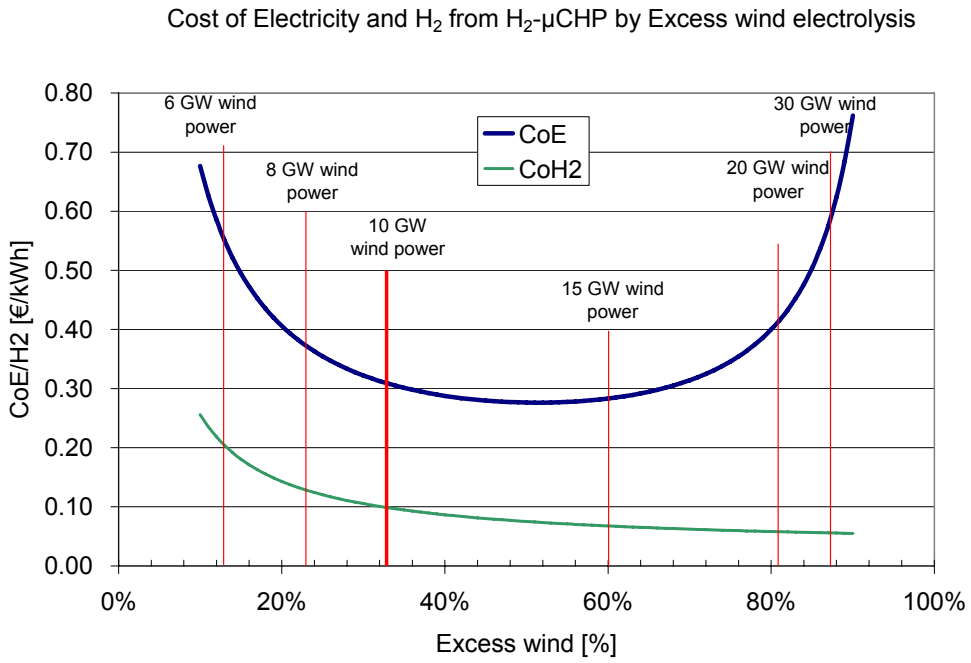


Figure 9: Cost of Electricity (CoE) and Hydrogen (CoH2) with variation of excess wind time. For CoH2 in €/kg, multiply by 33.6. For CoH2 in €/GJ, multiply by 278.

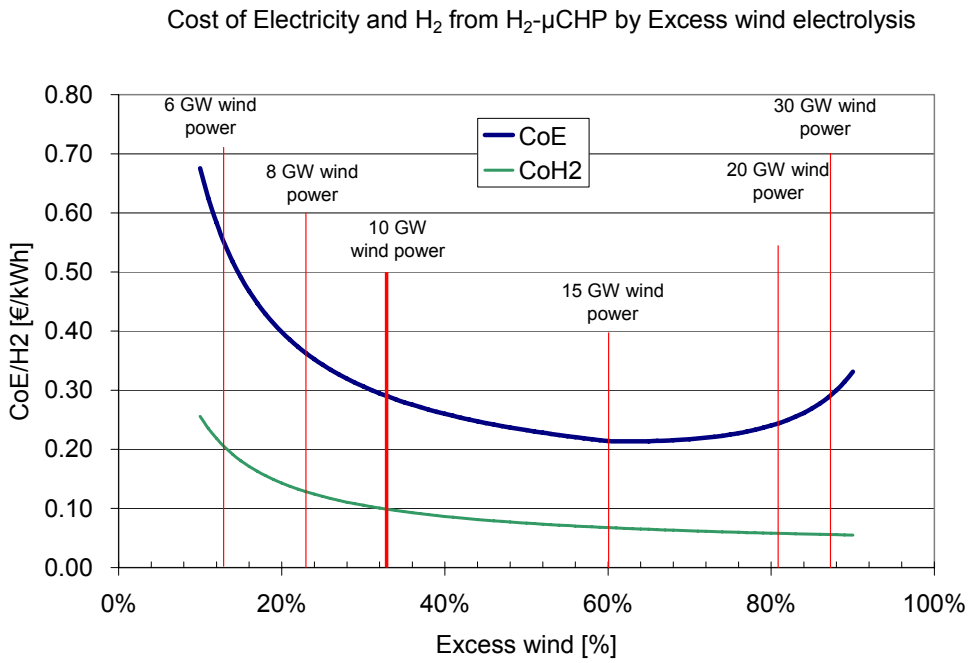


Figure 10: Cost of Electricity (CoE) and Hydrogen (CoH2) with variation of excess wind time. In this figure the optimal operation of the fuel cell with present day feed-in arrangement is used from Figure 6.

3. Regional market development in the Netherlands

3.1 Regions of interest

In the Netherlands 3 regions for the development of fuel cell systems and hydrogen applications are foreseen:

1. The Rijnmond area
2. Arnhem area
3. Friesland/Petten area

In the Rijnmond area an industrial hydrogen infrastructure exists which makes this a good starting point for hydrogen applications. In the Arnhem area local manufacturers of fuel cells and fuel processors are located. These companies are supported by the municipality for employment reasons. The Friesland/Petten area is interested because of energy sustainability initiatives at the Wadden islands, the support by the province of Friesland and the research infrastructure in Petten.

Two communities are identified that are interested in housing fuel cells for households in the near future: Leeuwarden and Arnhem. Both communities state that for financial reasons (subsidies and risk) a demonstration project for fuel cells in households should be for maximum 20 households. In Arnhem also a citizen initiative (De Stoere Houtman) for renewable energy with hydrogen as buffer/energy carrier is started for 138 existing dwellings and 150 new dwellings.

De Stoere Houtman has opened a dialog with hydrogen application experts and officials at the European Commission Directorate-General of Energy and Transport. Since 2004 they are member of the Business Development Group within the EU H2 Platform. They take this as a sign that 'Brussels' is showing interest in De Stoere Houtman's project as probably Europe's first "citizens' initiative" for a pilot project in applying hydrogen in the energy household of a residential area and perhaps even worldwide. The first desk study [4] indicated that for safety reasons a hydrogen grid into the houses is at this moment a step too far, e.g. standard odorants for natural gas are not suited for hydrogen because the low density of hydrogen causes separation of odorant and hydrogen.

3.2 Stakeholders

The view of the stakeholders:
At the moment there is no excess wind energy available in the Netherlands. The interest from the wind energy sector is to provide more reliable energy in order to obtain a higher price for their electricity, for which energy storage is an option. There are scarcely interested stakeholders from the wind energy sector.

For a demonstration project the communities Leeuwarden and Arnhem are interested in renewable produced hydrogen because of exposure of the community to the outside. For this they are willing to provide some financial contribution. They have no money to support large scale application of the technology. The low round trip efficiency of 30% of the system is considered too low to make this system attractive and have perspective [B. de Boer; Prov. Friesland].

The citizen initiative of the "De Stoere Houtman" is interested in sustainable energy systems that use hydrogen for energy storage in their district. No hydrogen grid to the dwellings is foreseen because of safety reasons.

The company NedStack is interested because they produce PEM fuel cell systems. They haven't yet demonstrated a specific system for this application. They consider the round trip efficiency too low and the system costs for these small systems too high for making a market out of this. They see some market for 100-250 kW mini-CHP systems for small communities.

Air Liquide, Linde and Air Products, all industrial producers of hydrogen, are interested in extension of the applications of hydrogen and hydrogen delivery systems in hydrogen fuelling stations for transport and/or large stationary applications.

The Energy research Centre of the Netherlands (ECN) is interested in initiatives and support for fuel cell system demonstration and hydrogen transitions experiments. Low round trip efficiency, supply of neither the complete electrical nor the complete heat demand, too high cost and more efficient alternative storage technologies prohibit the market development of this technology.

SenterNovem is the Dutch organisation that provides the subsidies for energy projects. They state that no "green" electricity should be used for hydrogen production due to the high conversion losses [6].

There is no stakeholder from the electrolyser sector active in the Netherlands.

An overview of the qualifications and the different actors is given in the next table. There is no stakeholder that possesses all qualifications and therefore there is a problem in the implementation of the excess wind to micro-CHP fuel cell system.

	Wind firms	Community	Citizen	NedStack	Air Liquide	ECN	SenterNovem
Interest		x	x	x	x	x	x
Power		x	x				
Organisation	x	x		x	x	x	x
Information	x	x	x	x	x	x	x
Access	x			x	x		
Knowledge				x	x	x	

4. Conclusions

The conclusions from the economical section are:
The efficiency and cost of electricity perspective for large scale integration of excess wind energy via electrolysis to hydrogen production and storage for micro-CHP systems for households is investigated. This process is a possibility to solve the unbalance of electricity supply and demand in time. In the process about 50% of the energy is lost, 31% is recovered as electricity and 17 % as heat assuming electricity load following operation. The cost of electricity (without taxes or profit) of this application, using target costs for the system components, is for the Dutch situation already higher than the present day mean consumer electricity price (with taxes and profit). The perspective of excess wind energy via hydrogen to micro-CHP for household applications is therefore very low.

With the micro-CHP system nor the complete electrical demand, nor the complete heat demand can be covered. This means that the house needs to be connected to the electrical grid and the heating requirement should be solved by natural gas, heat pumps and/or solar collectors. Solving the heat requirement by hydrogen burning is not attractive. Hydrogen provided in this way has approximately twice the cost of natural gas, the amount of hydrogen from this process is relatively small and seasonal storage is too expensive.

The conclusions from the stakeholder analysis are:

No strong stakeholders for this system and application are identified. Knowledge and technology providers see no market in hydrogen based household fuel cell systems.

At the moment, the only, unrealistic, possibility for development of large scale integration of excess wind energy via electrolysis to hydrogen production and storage for micro-CHP for households would be that the government sets obligations on the number of specific units to be installed by the electricity production companies and that the government forces a hydrogen grid to be installed. This is also unlikely in the views of the liberalisation of the energy market.

Overall conclusion:
Considering above conclusions, market development of excess wind energy via electrolysis to hydrogen production and storage for fuel cell micro-CHP for household applications is inappropriate for the Netherlands for the next decennia. Demonstrations of these systems should not be supported since these systems lack economical as well as efficiency perspective compared to alternative systems like redox flow batteries of pump accumulator systems.

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TenneT - Other publications
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[6] . Waterstofwegwijzer_SenterNovem_Kansrijk

Contents

1 Description of the regional market in Navarra

With nearly 600,000 inhabitants and a surface area of some 10,391 Km^2 (2% of the Spain area), nowadays Navarre is one of the main regions in the world in electricity generation from renewable sources, fundamentally wind energy. Navarra covers around 68% of its electrical demand whit renewable energies, 51.7% comes from wind energy.

Figure 1.Navarra location.

At the end of 2006 the installed power with renewable energy in Navarra was 1,247 MW, 917 MW come from wind power. Earlier studies by Red Eléctrica de España (REE, It is the responsible for the transmission network and for operation of the Spanish electricity system) indicated a cap on wind power production of 1,400 MW, considered as the maximum the network could accommodate.

Currently Navarra has set temporary suspensions in the handling of requests for installations for new wind farms or in approving new strategic wind farms due to the large number of requests for administrative authorisations made after the approval of the appropriate regional standards. This moratorium is related to the temporary saturation of the capacity for evacuation of the electrical grid and also with planning criteria for implementing new wind farms.

This problem could increase if a repowering in the wind farms will be made. Therefore, we need a solution to increase the integration of this energy in our generation mix and that way obtain a progressive increase of renewable energies and a reduction in fossil fuels dependency.

In this project we try to solve part of this problem using the “excess” of wind power to produce hydrogen by means of electrolysis and then storing the hydrogen to use it in a 1kW CHP PEM fuel cell to cover part of the household energy demands.
The system diagram is shown in Figure 2 below.

2 Regional market description

The average electricity demand in a 90 m^2 household in Navarra is 3,500 kWh/year, this represents approx. 30% of end-energy-use.

In this project a 1kW CHP PEM fuel cell is meant to be used, with this power we can provide 90% of the household energy consumption.

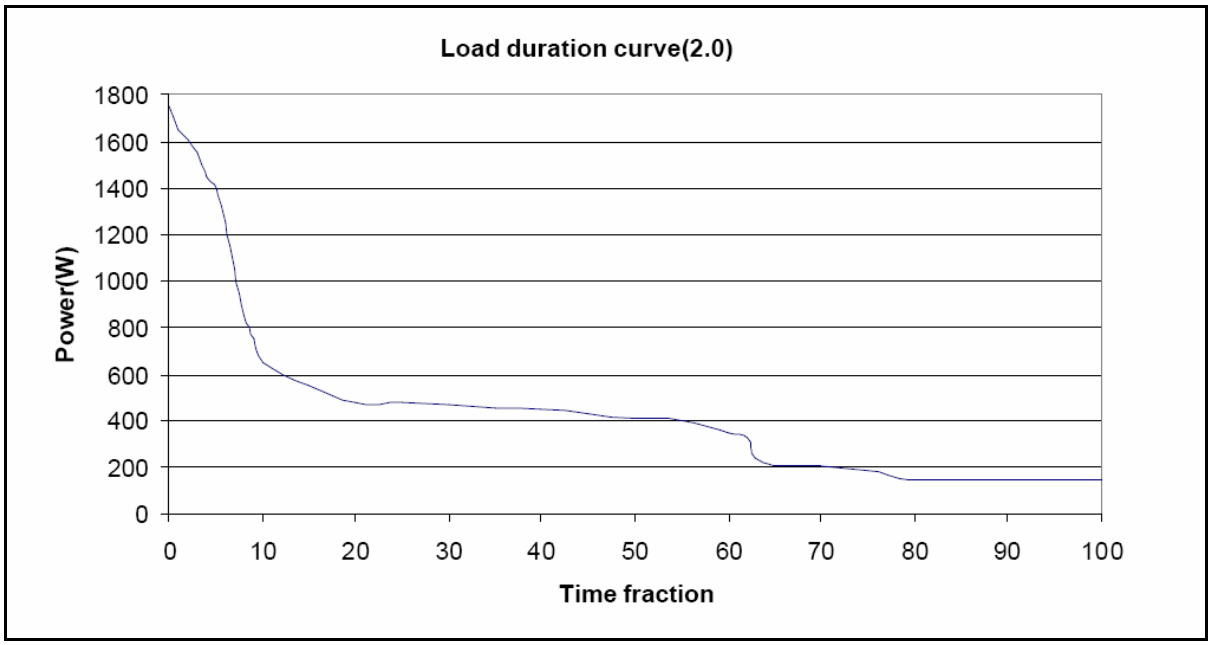

Figure 3. Load duration curve for households in Navarra.

The hydrogen will be produced during the night when energy availability is high and electricity price is low and then, during the day the fuel cell will be supply the energy demand in the household.

The fuel cell will be connected to the grid, in such a way that if we have enough hydrogen to produce electricity with the fuel cell and we don't need all this power, we can feed into the grid the surplus electricity to obtain a feed in tariff.

In may 2007 there was published a new Royal Decree (R.D. 661/207) in which there is regulated the purchase of surplus electricity supplied by CHP fuel cell systems to the distribution company at a price of 12,04c€/kWh, quite higher that the previous tariff (approx. 7c€). This would be an added benefit to the end users to install this technology in their household.

3 Regions of interest

In Navarra there are two possible regions to carry out this project:

- **Sarriguren.** This region is 5 Km form Pamplona (the capital of Navarre), in the same region where Cener (Centre National of Renewable Energies) is placed. This location has been chosen by the special characteristics because this is an eco city (ecological city). All the households are built based of the principles of bioclimatic architecture: energy saving, integration of renewable energy and application of the "healthy building".

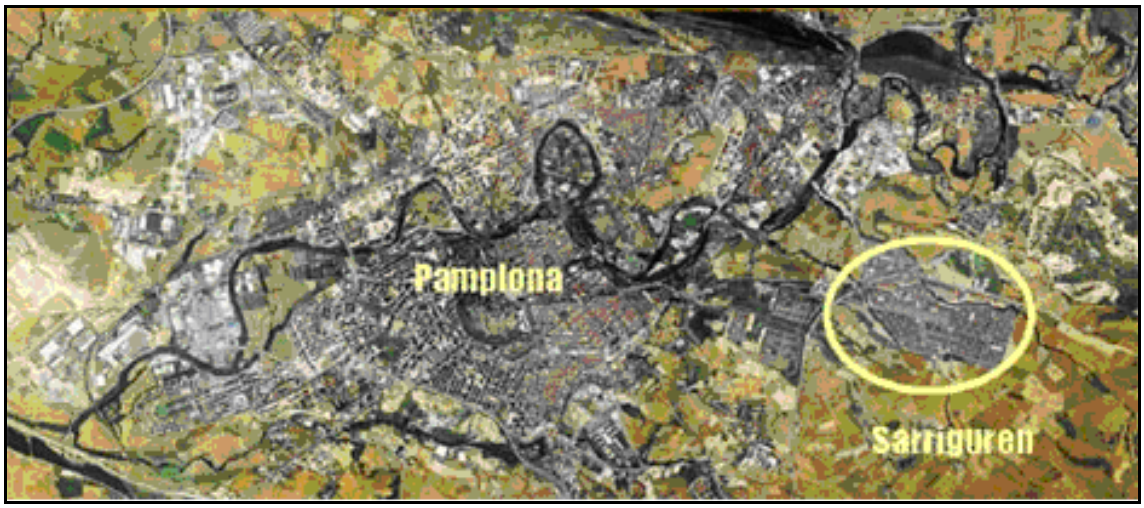

Figure 4. Sarriguren location

- **Tudela.** This region is located 90 km south of Pamplona. It has been selected because Tudela is one of the participating ECO-City demonstration communities. The target of this project is to reduce energy demands and to provide energy efficient (EE) solutions to integrating the maximum use of renewable energy sources.

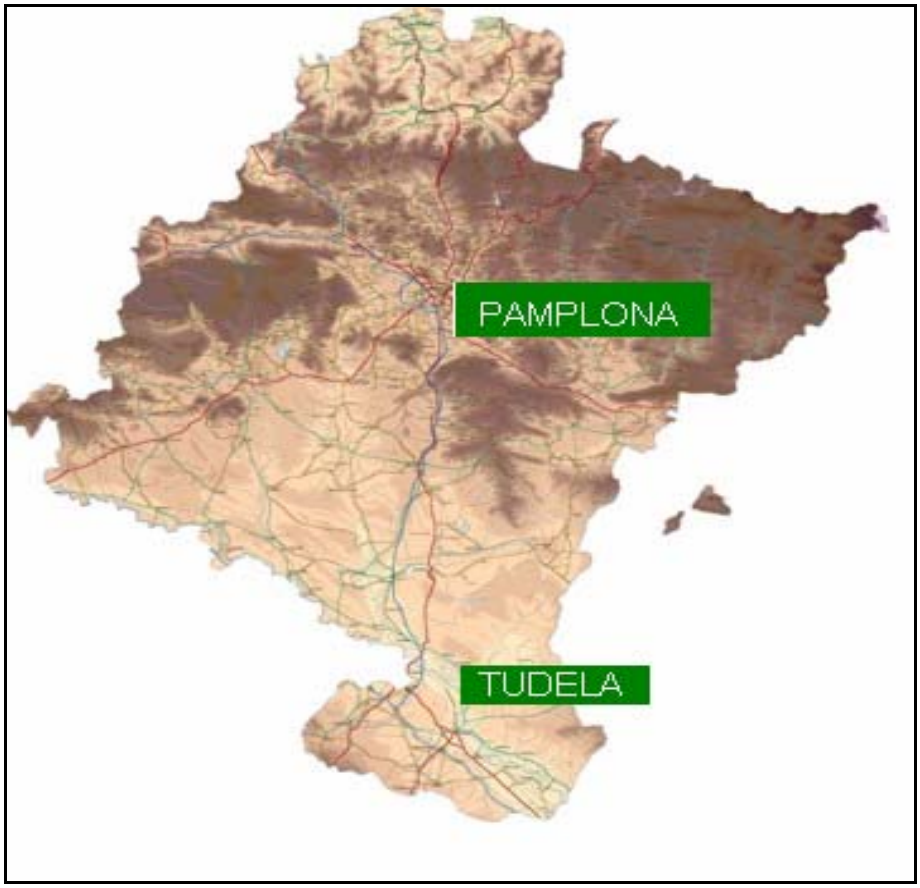

Figure 4. Tudela location.

4 Barriers against RES FC Systems

In the study of the hydrogen from “excess” wind energy integration in the household by means of a CHP fuel cell to cover the energy demands in Navarra, we have found some barriers.

- One of the foremost barriers to the introduction of this technology is the high cost of the components, hydrogen production (electrolyser), storage and hydrogen conversion to electrical or thermal power (fuel cell)
- Nowadays in Navarra no hydrogen grid exits.
- 1kW CHP PEM fuel cell is not enough to supply the whole household energy demands, therefore the house would be connected to the electricity grid to supply the peaks power and would have other systems to cover the thermal needs (i.e. natural gas boiler).This is an additional cost to the end users.
- Another barrier that we have found is the short guaranties of the fuel cell. The household promoters do not want to run risk to install these systems in houses if fuel cells don't have enough use and efficiency guaranties.
- Another important problem is the lack of legislation related to the use of hydrogen in residential sector, which makes the installation and maintenance difficult.
- There is a general lack of knowledge about hydrogen and fuel cell technologies in the society and from the household promoters, so a large use of these technologies by the population is difficult.
- There exists an apparent lack of government support for the development of fuel cell technologies in Navarra to date. Although the government is promoting the use of renewable energies, in the residential sector the Spanish government obliges to install solar energy in new households, promoting this source of energy against fuel cells. The competence with other technologies, that are cheaper and easier to install but less efficient and more worthwhile, is really important.

5 Potential solutions to overcome the barriers

- It is necessary to make efforts in R&D to improve efficiencies, reliability, lifetime, and materials performance. Thereby this technology could be more competitive with the technologies that are used nowadays.
- It would be necessary to offer to fuel cell manufactures a market niche and in this way they could begin to manufacture components in mass to reduce cost.
- According to the household's promoters, in Navarra it would be more interesting to use a 1 kW_e + 3 kW_{th} CHP fuel cell. If this type of fuel cell is used into the house it wouldn't be necessary to have an extra system to cover thermal needs.
- It is necessary to make a good study about the size of fuel cell thereby, the end user could feed into the grid the surplus electricity to obtain a feed in tariff, making this system more economical.
- Increased Government support both in terms of legislative reform and financial support is necessary to enable hydrogen technologies to reach commercialisation and to establish a sustainable position in the market. Subsidies for demonstration models could be one way forward.
- It will be necessary a lot of dissemination activities about hydrogen technologies to encourage the concept of clean energy among the general public and to increase the knowledge about the hydrogen economy. Thereby the end user will be interested in using fuel cells in their households.

6 Stakeholders involved in the regional market

- **Wind sector.** Although there is no "excess" wind energy at the moment, because all that is produced is feed into the grid, in the near future we will be "excess" of wind power due to limitations in capacity for electricity evacuation. Nowadays wind farms promoters don't make efforts to produce hydrogen from wind energy.

- **Government.** Navarra's Government is encouraging all renewable energies. In the residential market the most important are solar energy and biomass. They are full developed and they offer good results in the households.
- **Communities.** Nowadays there are two regions in Navarra that are developing eco-cities: Sarriguren and Tudela, however it will be necessary a great effort and a huge cost reduction to introduce hydrogen from wind power into the households.
- **Citizen.** There is a general lack of knowledge about hydrogen and fuel cell technologies in the society.
- **Fuel cell manufacturers.** Some fuel cell manufacturers that we have contacted are interested in residential fuel cells, but their products are focussed on the automotive sector, because this sector was the first niche market that they considered.
- **Electrolyser manufacturers.** In Spain we have not made contact with any manufacturer of electrolysers, but in Europe there are some companies with experience in this sector that are related to Spain.
- **Hydrogen supplier.** There are some companies that deliver hydrogen to the laboratories, however in Navarra no hydrogen grid exits.
- **Household's promoters.** There are some promoters that build houses with a great energy efficiency, who are interested in this technology, but they don't have so much technical knowledge about hydrogen and fuel cell.

In the table below is shown an overview about the more important actors related to this project.

	Interest	Power	Organisation	Information	Access	Knowledge
Wind sector			X	X		
Government	X	X	X	X		
Communities	X	X	X			
Citizens	X					
Electrolyser manufacturers	X	X	X	X	X	X
Fuel cell manufacturers	X		X	X	X	X
Hydrogen suppliers	X	X	X	X	X	X
Household's promoters	X		X	X		

The foremost barrier in the society and from the household promoters is a general lack of knowledge about hydrogen and fuel cell technologies, so it's difficult a large use of these technologies if end users don't know too much about the possibility to use fuel cells to produce heat and electricity in their houses. The owners of the households don't know how fuel cells work, all their advantages and furthermore this technology is too expensive for them.

Manufactures of fuel cell don't have enough confidence in the introduction of this technology in residential sector. They bet on other sectors more attractive for their business.

Household's promoters are interested in hydrogen and fuel cells in spite of the high cost of these systems, the lack of guaranties and legislation, but at the present time they are more interested in other technologies with renewable energies that are more advanced technologically and more cost effectives than hydrogen technologies.

Faced with all the barriers that we have found, a great encouragement from the Government and the energy industry is required in order to know the advantages that hydrogen and fuel cell could provide to the society.

It is necessary to make manufactures understand that they will find an important market niche within the residential sector, but they will have to make a great effort to adequate their facilities to manufacture mass production components to reduce the cost. It will be necessary as well to make an effort in R&D to improve efficiencies, reliability, lifetime, materials performance and guaranties.

Within the wind power sector, hydrogen will be the solution to their problems about “excess” wind, and producing hydrogen from wind energy they could increase the integration of this energy in our generation mix.

It will be necessary to get a great Government support both in terms of legislative reform and financial assistance to install the first systems based on hydrogen and fuel cells. It will be necessary to promote the research in all the fields related to the hydrogen: production, storage, distribution and energy generation (fuel cells), and to support companies that are working on hydrogen.

7 Conclusions

The purpose of this part is to explore the barriers and opportunities for the development of hydrogen technologies in Navarra (Spain). The “excess” wind energy is used to produce hydrogen by means of electrolysis and then the hydrogen is used in a 1kW CHP PEM fuel cell to cover part of the household energy demands.
In Navarra there are two possible regions to carry out this project because of their interest in renewable energies, more efficient and less pollutant than conventional sources of energy, they are named eco-cities.

Therefore hydrogen technology is available, it is still relative young and unproven. The technology doesn’t have enough guaranties to use into the households, it is no cost effective and there is no hydrogen infrastructure and legislation.

Some fuel cell manufactures that we have contacted are more interested in automotive sector, so they are developing fuel cell for transport.

Another issue is that at this moment there is no “excess” wind energy, but in Navarra it will take into account in the near future, because of the 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, so it’s difficult a large use of these technologies by the population.

Spanish Government is promoting the use of some renewable energies, as solar energy or biomass, in residential sector because these technologies are more developed and they offer good results in the households.

Despite of all of those difficulties, if we could to carry out 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.
It will be necessary a lot of dissemination activities about hydrogen technologies to increase the knowledge about the hydrogen economy, making a great effort in R&D and reducing the cost of this systems by means of a large scale production.

Finally, if the Spanish Government promotes hydrogen and fuel cells as the same way as photovoltaic energy and fuel cell price decreases, systems based on hydrogen could be cost-effective.

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WP 3

Regional Market Development Plans

Coimbra Region, Portugal

Paula Fonseca

Contents

1 Brief description of the regional market

Coimbra is located in the centre region of Portugal. By the end of 2010 the country will have installed and operating about 5100MW of wind power generation [RCM nº. 169/2005], 40% of which will be installed in Coimbra Region.

The number of dwellings that could be possible for the market development plan implementation for 2010 in Portugal is 10. The location is a new construction site in Coimbra where there are being built new building blocks of three-four bedroom flats. This new buildings 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 in Portugal, with high electricity needs, amounts 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]. Space heating needs lasts 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 in Portugal.

Typically, electric heating represents 28% of the total electricity consumption in a household in Portugal, amounting 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.

However it should be noted that cooling is increasing fast in Portugal because of the average temperature increase and also because of the increasing standards of living and comfort level increase.

The choice of wind/hydrogen as main technology element for the RES-FC Market in Portugal is related with the fact that it is a country with very good conditions for wind power generation. Wind power resources are mainly available in the north and central region – in the high and rocky places, with an average wind speed of about 6 to 7 meters/second. There is a high potential for the installation of more wind power in Portugal; the wind resource is high and its exploitation is economically attractive because of government support, but there are some constraints, in particular grid interconnection issues because of the limited reception capacity of the network. About 400 MEuros are being invested in the expansion of the transmission network to increase the capacity to integrate wind power. However, further expansion is limited by the capacity to integrate larger amounts of intermittent generation. A possible solution to expand this generation could be to use the excess wind power to produce hydrogen through electrolysis process, which will be used to provide heat, electricity and hot water to the households.

Table 1 presents the installed wind power and electricity production in the central region in recent years.

Table 1 - Installed wind power and electricity production in central region

	Power (MW)			Electricity generation (GWh)		
District	**2004**	**2005**	**Dec. 2006**	**2004**	**2005**	**Sept. 2006***
Aveiro	5	5	128.1	9	10	14
Castelo Branco	13	33	147.2	19	68	84
Coimbra	60	185	250.1	82	204	287
Guarda	12	12	84.7	5	25	32
Leiria	10	60	124.2	1	98	100
Santarém	31	89	103.9	25	120	215
Viseu	98	137	183.7	201	277	260
Centre Region	**229**	**521**	**1 021.9**	**342**	**802**	**992**
Total Portugal	537	1 047	1 716.4	787	1 741	1 802
% of Centre Region	**42.64%**	**49.76%**	**59.54%**	**43.46%**	**46.07%**	**55.05%**

* It was not possible to get information on the electricity generation by region by Dec 2006.

Table 2 presents the total wind power that will be installed till 2010 in Portugal.

Table 2 - Total wind power installed till 2010 in Portugal

Regions	**MW**	**%**
Beira Litoral	969	19
Beira Alta	663	13
Beira Baixa	408	8
Total Coimbra Region	**2040**	**40%**
Minho	765	15
Trás-os-Montes e Alto Douro	714	14
Alto Alentejo	510	10
Estremadura	816	16
Algarve	306	6
Total	**5100**	**100%**

In Fig. 2 it can be seen that unlike the hydro power whose load variation is highly dependent on the season, the electricity production from wind power generation is almost constant all over the year in Portugal.

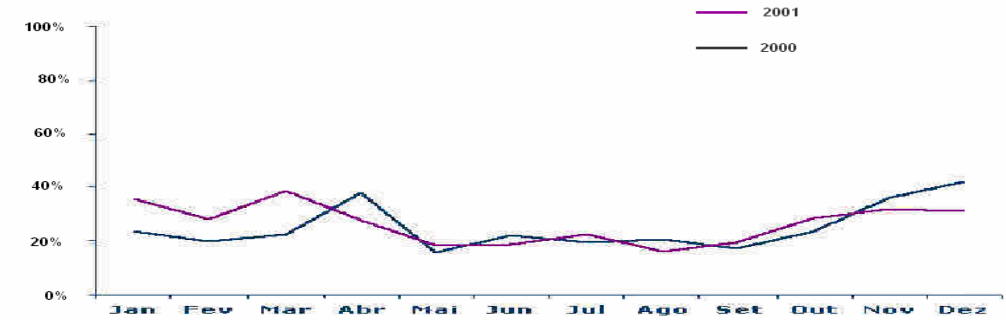

Figure 2: Season variation of load factor of wind power in Portugal

Fig. 3 shows the stability of the wind power generation in full load hours per year in the last 10 years and it can be seen that there are good conditions to increase wind power plants in Portugal.

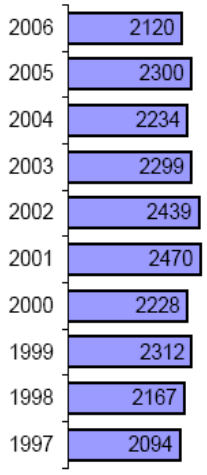

Figure 3: Hours of wind power generation per year

Although these good conditions for using wind/hydrogen as main element in the market development plan excess wind power generation is not available by the time being in Portugal. This situation is an important barrier for the market development plan.

However, this situation could change in the near future because, at present time, on average one 2MW wind turbine is being installed every day in Portugal.

Lack of excess wind power – alternative solution for Central Region (PO)
Because of the new government strategy of using excess wind power to develop the reversible hydro plants (pumped storage), other options than to promote fuel cell households may be considered and deserve to be investigated in the central region of Portugal. In fact, there is another alternative possibility to promote fuel cells in the residential sector in Portugal, by using cleaned biogas from sewage treatment plants, urban solid waste and residues from farms. The existing potential of biogas has been therefore investigated with the only objective of showing an alternative that is not negligible; however, excess wind power remains the technology element for the centre region, as it is the contractual commitment with the Commission. Presently in Portugal there are about 100 systems of anaerobic digestion applied to:

- Large Agro-Cattle and Agro - Industrial installations – 71

- ETAR´S (Residual Water Treatment Stations) and RSU (Urban Solid Waste) – 29

Fig. 4 presents the distribution of anaerobic digestion systems and the source of the waste distribution.

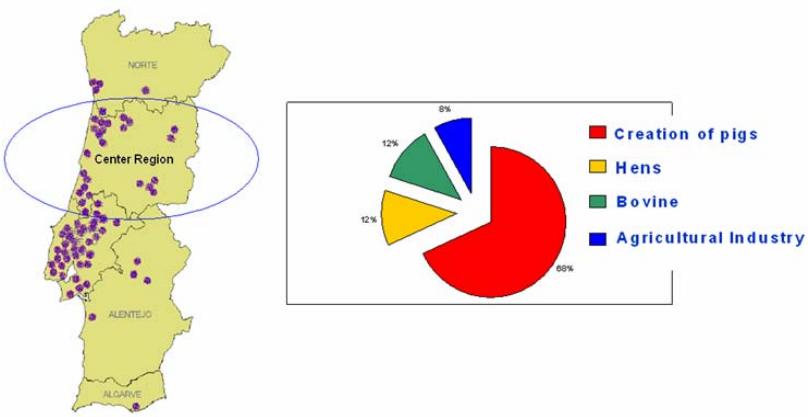

Figure 4 – Geographic localization of anaerobic digestion systems and the distribution of waste production by source

In March 2007 there were 8.2 MW of biogas installed power in Portugal that were responsible for the production of 33 GWh of electricity with an operating time of 3857 hours. The annual evolution of hours of generation is presented in Fig. 5 for a period of 9 years, as well as the electricity production vs. installed power due to biogas.

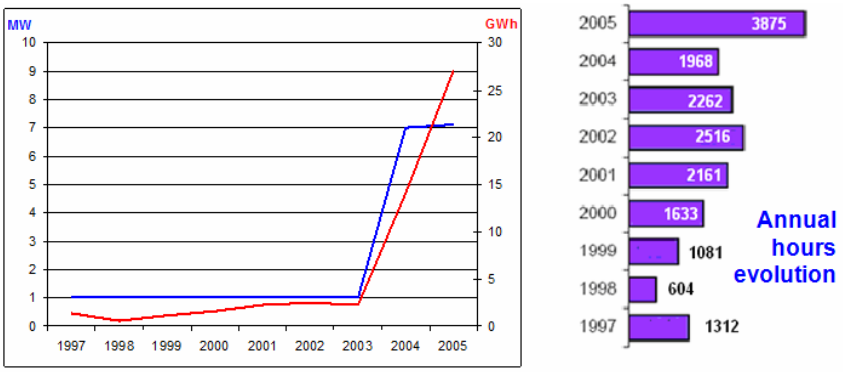

Figure 5 – Electricity production vs. installed power due to biogas and evolution annual of full load hours of generation

As an example, Fig. 6 presents a case study for an application with generation of biogas to produce hydrogen for feeding fuel cells that is being implemented in Montemor-o-Velho/Cantanhede, centre region, based on waste from bovines, which are being bred in this area.

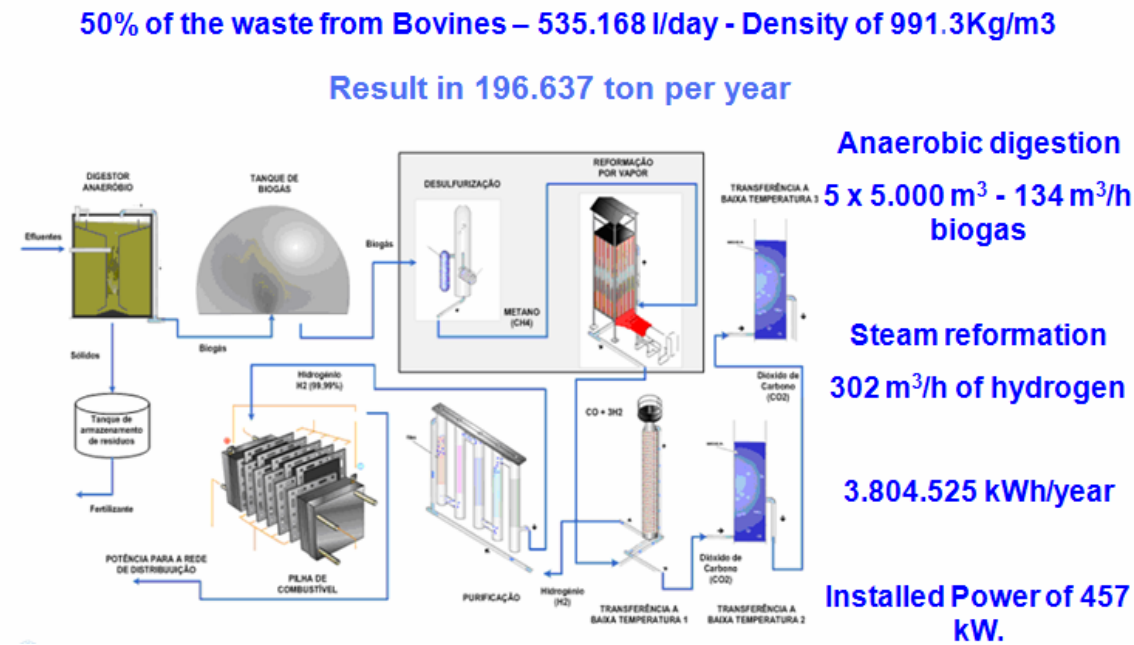

Figure 6 – Case study in Montemor-o-Velho/Cantanhede

There is a high potential for biogas application with fuel cells in the centre region in Portugal. In addition there are also some key players in the market who have been more and more interested in promoting this type of technology.

2 Brief description of the framework conditions and barriers

Immaturity and the high cost of the technology are among the main factors preventing the development of FCs for household applications worldwide. In addition, in Portugal there is a significant constraint for the creation of the RES-FC Market which is due to the fact that at the present time, there is no excess wind power generation and there is the possibility that this situation could continue in the future since the strategies of the Portuguese government for renewable energy sources have changed. In particular the expansion of reversible hydro in the actual hydro power plants is now on the top of the political agenda and is already being developed.

Many times, wind power plants are implemented in remote locations making it more difficult, less efficient and more expensive to supply the targeted households with electricity to produce hydrogen.

In the beginning of this project, the situation was quite different in terms of the installation and use of wind power plants. There is a high potential for the installation of more wind power in Portugal; the wind resource is high and economically attractive because of the government support, but there were some constraints, in particular grid interconnection issues. The integration of wind power into the grid was by that time, the most important constraint to the development of future wind power, because of the limited reception capacity of the network. The expansion of wind power was limited by the capacity to integrate larger amounts of intermittent generation. One possible solution identified was to use the excess wind power to produce hydrogen through electrolysis process, which could be used to provide heat, electricity and hot water to the households. However, the government strategy has recently changed and a lot of money has been invested in the expansion of the transmission network to increase the capacity to integrate wind power. Now, the new strategy is directed to use excess wind power in connection with reversible hydro power plants.

Legal framework conditions

Independent power producers and auto-producers using Renewable Energy Sources (RES) and Combined Heat and Power (CHP) plants are covered by a specific legislation, which is not under the responsibility of the regulator (ERSE). This legislation obliges the Public Service System to buy the electricity produced. The price is defined by legislation as follows:

- up to 10 MVA, it is index-linked to one option of the regulated retail prices modulated by the time of the day;
- for the part of the electricity sold over 10MVA, it is based on avoided costs, plus remuneration for the environmental externalities avoided.

Since July 1995, as part of the new legal framework of the National Electricity System, the combined production of heat and electricity is regulated by an autonomous legislation: Decree-Law no. 186/95 of July 27, 1995. Afterwards, in order to adjust the contents of Decree-Law no. 189/88 to the new framework, Decree-Law no. 313/95 of November 24, 1995 was approved. Nevertheless, in later years, the energy sector, in general, and the electricity sector, in particular, has faced two important modifications:

- The development of a single internal energy market.
- The increasing pressure of global environmental challenges.

The first development is responsible for the adoption of EU directives aiming to liberalise the energy sector operation.

The second obliges to reinforce the integration of energy and environmental policies aiming to fulfil international commitments on the reduction of greenhouse gas emissions.

Therefore, the existing legal framework (DL189/88 and DL313/95) regarding power production from renewable energy sources was revised by Decree-Law no. 168/99 of May 18, 1999.

Decree-Law no. 168/99 introduces a full change to the feed-in tariffs applicable to the sale of electricity from renewables, establishing the principles to account environmental benefits of power generation from renewable energy sources and creating an opportunity to implement green tariffs. Additionally, Decree-Law no. 168/99 re-organizes the permission process for RES power plants - describes the general arrangements, lays down the principles and establishes the rights and duties of all parties involved. Last but not least, Decree-Law no. 168/99 modifies the mechanisms to define the interconnection points of power plants, in order to assure an increased transparency to the procedures and equity between promoters.

Under the conditions of the resultant legal diploma - DL189/88 with changes introduced by DL313/95 and DL168/99 – the power producers had the guarantee that the electricity produced should be bought by the public grid during the license period. The feed-in tariff is based on the sum of parts related to:

The avoided costs for the Public Power System due to the starting-up and operation of the power plant, including:

1. The avoided investment cost on new power plants.
2. The transport, operation and maintenance, including fuel costs.
3. The environmental benefits from the use of endogenous energy resources.

Appendix II of the Decree-Law presents the formulae to calculate the feed-in tariffs and the time period that each formula is in force. The environmental part of the tariff is based on the unit valuation of the avoided CO2 emissions of a reference plant:

- 370 g (CO2)/kWh and 7.5€c/Kg.

According to the Portuguese Electricity from Renewables Association, the following highlights of Decree-Law no. 168/99 of May 18, 1999 deserve references:

- Buying obligation by the national grid of all electricity generated by renewable energy plants during the period in which the licences are valid.

- Implementation of a green tariff with an average value of 0.06 €/kWh (1999), higher than the former "base" tariffs of 0.047 €/kWh (1999) and 0.052 €/kWh (1998). Increased "guaranteed buy" period of 12 years (against the former 8), through a green tariff specific for renewable energy. After the 12 years, the buying price calculation is defined and the environmental benefits are partially accounted for.

- Regular updates of the tariff based on the consumer price index and no longer as a function of the selling price of electricity.

This is a real mechanism to internalize higher internal costs of other generating techniques (DR, 1999). In some cases, electricity produced from renewable energy sources has higher costs than that produced in other power plants connected to the public service system. This eventual additional cost is included in a component of a non-bypassable levy - "global use of the system" -, which applies to all users of the transmission grid.

In 2001, a new Decree Law, DL nº 339-C/2001, dated 29/12/2001, was approved. This act intended to modify the Act Nº 168/99, introducing important modifications in the feed-in tariff, according to the technology used to produce electricity and giving special focus to those emergent technologies, such as photovoltaic and wave power, which potential is high at a medium term. This law establishes environmental rewards for those installations that are using renewable sources to produce electricity and for CHP plants.

Table1: CHP technologies purchase rates in Portugal (feed in tariff)

Type of technology used	€/kWh
Otto cycle motors	0.01
Gas microturbines	0.015
Stirling motors	0.02
Fuel cells	0.2
Photovoltaic cells	0.2
Other autonomous equipments	0.015

Another important Decree Law, DL nº 312/2001, dated 10/12/2001 establishes the main points to manage the reception capacity of the Public Electricity Supply Service (SEP) grids derived from:

a) Generation of electric power in hydro power generation systems till 10MVA of installed apparent power;
b) Generation of electric power from renewable resources or from industrial, urban and rural solid wastes with the exception of hydro power generation;
c) Generation of electric power in co-generation systems;
d) Generation of electric power from the liberalized electric system (SENV).

Decree Law nº 68/2002, DR 71, I SÉRIE A, dated 25/03/2002. 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 this surplus capacity that can be sold to the grid is 150kW. According to this law, a micro generator is the main autonomous equipment that produces energy such as: motors, micro-turbines or fuel cells, which use synchronous or asynchronous generators, photovoltaic cells and other autonomous electricity production equipments.

Regulation nº 764/2002, DR 149, I SÉRIE B, dated 1/07/2002. The Law nº. 68/2002, of March 25 established rules for the low voltage electric energy production activity, and has created the low voltage electric energy producer-consumer "player", within the Independent Electric System. (SEI). According to nº 2 of the article 7, the tariff system should consider the avoided costs of the Public Service Electric System (SEP) that would be necessary to additional electricity production which is delivered to the grid by the co-generator and the environmental benefits associated with the better efficiency of the co-generation installation.

The Decree Law no. 33-A/2005, dated 16/02/2005 introduces changes to the previous legislation related to renewable energy production.

This Decree Law changes the formulae to calculate the feed-in tariffs and the time period that each formula is in force. The environmental part of the tariff based on the unitary valuation of the avoided CO2 emissions of a reference plant is changed to:

- 370 g (CO2)/kWh and 2€c/Kg.

More recently a new Decree Law for self producers based on renewable, was approved in 13/09/2007. This law will allow the end-users to produce electricity in their own houses and to sell the surplus production to the grid, as long as it does not exceed 150kW.

The Decree Law stimulates the production of electricity from micro generation units, which can be made from photovoltaic panels, mini-eolic turbines, co-generation from biomass or fuel cells. This new law also intends to simplify the bureaucratic process that used to be in force to get licenses.

The feed in tariff will be 650€/MWh, guaranteed during the first five years and after the 5 years, the in force tariff will be applied.

With this measure, the government intends to obtain a total power of 165MW that is produced from micro generation till 2015.

In the USA, the IEEE Standards Board approved IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems.

Many of the technical barriers that the distributed companies of electricity usually raise for the Distributed Generation (DG) interconnection with the grid are related to reliability, security and quality of service.

This IEEE standard defines interconnection technical specifications and requirements that are universally needed for interconnection of DG. This standard constitutes an important step to overcome the barriers and increase the development of Distributed Generation installations.

This American standard, establishes criteria and requirements for interconnection of distributed generation (DG) with electric power systems (EPS). It provides requirements relevant to

the performance, operation, testing, safety considerations, and maintenance of the interconnection.

The standard applies to all DR technologies, with aggregate capacity of 10MVA or smaller at the point of common coupling, and to all electric power systems at typical primary and/or secondary distribution voltages.

At present time, in Europe there are no standard definitions for the interconnection of distributed generation into the grid, like the present IEEE 1547. This lack of standardization also constitutes a main constraint for the integration of the distributed generation into the grid, and therefore there is a need for standardization in Europe.

Public financial support
A few years ago, in the framework of the POE (Operational Economy Programme), organizations in Portugal could get financial support from the government, by submitting proposals within the scope of the POE.

To be considered, an organization had to meet the specific eligibility requirements defined in the applications and submit a complete application. However this financial support mechanism was ended by March 2006. Since then, no further financial support/incentives had been active. Only incentives for wind power and PV power plants are possible.

Barriers based on WP2
The main barrier for a regional RES-FCHS market in the centre region is the cost of the technology. To reach households in Portugal is quite difficult especially if we take into account the economic constraints that are affecting Portuguese households in general.

The following barriers need to be overcome:

- High Price of technology: electrolyser, fuel cell, etc.
  For example:
  - Intelligent Energy Fuel Cell with CHP, 2 kWel and 2 kWth-2 – about 37000€
  - Hydrogenics electrolyser with 8 Nm^3/hour of H_2, 34 kW, 2.5 MPa (25 bar) rated – about 211000€

  These values are indicative costs taken from the report of the "hydrogen and renewables integration (HARI)" - Rupert Gammon, Amitava Roy, John Barton, Matthew Little - CREST (Centre for Renewable Energy Systems Technology), Loughborough University, UK

- No significant excess wind power**:** Although the significant increase in installed wind power in Portugal (1700MW by the end of 2006 and around 5100 MW in 2010), the government strategy is to develop the reversible hydro plants, using the excess wind power;

- No hydrogen network, hydrogen storage and transportation are a major concern because of security issues and also because of the price of the technology. There is no legislation on hydrogen security;

- Remote location of wind power plants;

- System efficiency: cascade efficiency can be very low. It is estimated that the full-cycle efficiency to be low);

- The Feed in tariff (0,20-0,30 €/kWh) may not compensate. Wind power producers are paid 0,09 €/kWh. Therefore the cost of producing 1 kWh with H2 fuel cells may be higher than the feed in tariff;

- Lack of government/stakeholders interest; investments are more targeted to wind, solar, biogas and bio fuel, than for FC technologies;

- Lack of financial incentives; There was in the past a programme to support investments in new energy production technologies (micro generation technologies), but this is no longer running. A new microgeneration law is under consideration which may provide strong incentives;

- A short heating season in Portugal is also reasons to hinder FC developments for CHP applications.

3 Identification of relevant stakeholders

Energy Supply

The chosen location for developing the RES-FC Market is a new construction site in Coimbra. This construction area was chosen because of the interest of the constructor of the buildings in the project. The closest wind power plant (Vila Nova - 20MW) is located in Lousã, a small town very close to Coimbra (about 30km south-east Coimbra). The company responsible for the exploration of this wind plant is Enernova – Novas Energias S.A.

This company is a member of the EDP group and is responsible for wind power generation projects. At present time, Enernova is the major company of wind power generation in Portugal and they are expanding their wind plants all over the country.
Due to the distance of the power plant to the location of the RES-FC Market site, the energy to produce hydrogen for the fuel cells has to be supplied from the electric grid.

The company responsible for energy sale to end users is EDP Distribuição.

Energy Transformation

Electrolysers

Teledyne Energy Systems, Inc. (TESI), a Teledyne Technologies Company, is a leading global provider of on-site gas and power generation systems and fuel cell test equipment.

Tanks and Hydrogen Network

In relation to the storage tanks and the hydrogen network some contacts have been established with a delegate from Air Liquide – Portugal.
The Air Liquide group was founded in 1902, and it is the world leader in industrial and medical gases and related services. Their core business is to supply oxygen, nitrogen, hydrogen and many other gases and services to most industries (for example: steel, oil refining, chemicals, glass, electronics, healthcare, food processing, metallurgy, paper and aerospace). They are also involved in the field of fuel cells research, through their subsidiary AXANE.
Their global presence (130 subsidiaries in more than 70 countries) allows the group to combine the resources and expertise of a global enterprise with a powerful local presence based on independent customer-focused teams.
Air Liquide – Portugal has already collaborated in the past with ISR-UC in relation to other projects involving Fuel Cells (Research projects), and they shown a great interest in this project and are available to collaborate with the RES-FC project in Portugal.

Energy end-use
The number of dwellings that could be possible for 2010 in Portugal is 10. The location is a new construction site in Coimbra where new building blocks are being built. This new buildings are being constructed by the biggest constructor of the central region of Portugal, BASCOL – Construção Civil S.A. This company is always interested in new technologies that can improve the quality of their constructions and that can bring more advantages for their clients. They have shown a great interest in the project and they are also interested in collaboration.

Energy buyers
EDP Group is one of the major European operators of the energy sector, being the third largest energy operator in the Iberian Peninsula, and the largest Portuguese industrial group. EDP is the only company of the energy sector in the Iberian Peninsula with generation, distribution and supply activities in Portugal and Spain - where it controls the fourth largest Spanish electricity operator, HC Energía. In addition, EDP has a relevant position in the gas sector in the Iberian Peninsula, through the company Naturgas in Spain, the second market operator, and Portgás in Portugal, the second distribution company.

Internationally, and in addition to the Iberian Peninsula, the EDP Group has also a strong position in the Brazilian electricity sector, where it produces, distributes and supplies electricity through Energias do Brasil.

Ancillary Services Buyers
REN - Rede Eléctrica Nacional, S.A. holds the concession of the National Electricity Transmission Grid (NTG) in mainland Portugal. It provides a public utility service, which includes:

- Technical management of the National Electricity System (SEN) and overall management of the Public Electricity Supply Service (SEP);
- Transmission of electricity in very high voltage (400, 220 and 150 kV);
- Operation of the NTG and the construction, maintenance and planning of its infrastructures.

In fulfilling its mission, REN is responsible for ensuring the continuous supply of electricity by:

- Meeting quality and safety criteria;
- Maintaining the balance between supply and demand which implies forecasting electricity demand trends and identifying the need of new SEP generating centers and their possible location or strengthening the capacity of existing ones;
- Protecting the legitimate interests of the different players in the electricity market;
- Combining its joint role as system and market operator.
-

National, Regional, County & Municipal authorities setting framework conditions

DGEG - Direcção Geral de e Energia e Geologia. The DGEG is responsible for the planning and development of the Public Electricity System (PES), including the approval, issuing, amendment and cancellation of production and distribution licenses, as well as the prepara-

tion, every two years, together with REN (Rede Eléctrica Nacional), of the PES's expansion plans, subject to approval by the Ministry of Economy.

ERSE - Entidade Reguladora dos Serviços Energéticos
ERSE is the independent body responsible for the regulation of the natural gas and electricity sectors, executing its duties in observance of the main energy policy directives established by the government.

The ERSE's regulatory obligations and objectives are set out in accordance with:

- Decree Law n.º 187/95 of 27 July 1995 which established ERSE;
- Decree Law n.º 97/2002 of 12 April 2002 approving the ERSE articles of association and extending its competencies to the Natural Gas sector;
- Decree Law n.º 69/2002 of 26 March 2002 extending ERSE's responsibilities to the autonomous regions of Madeira and The Azores.

ERSE is responsible for supervising PES's operations (Public Electric System) and the relationship between SEP (Public Service Electric System) and SENV (Unbound Electric System) and regulating activities carried out within the SEP's framework, specifically establishing tariffs and prices for electricity and other services provided by REN and by the holders of binding distribution licenses.

These activities are governed by the following regulations:

- Tariff regulation - establishes the provisions concerning the criteria and methods for fixing tariffs and prices for electricity provided by the entities it covers;

- Regulation on commercial relations - regulates commercial relations within the PES, and between PES and the Non-binding Electricity System (NBES);

- Regulation on access to networks and interconnections - establishes the provisions concerning technical and commercial arrangements for access to the SEP networks and interconnections.

- **Licenses and Concession Regimes**

PES's electricity generation activity is subject to a binding license issued by DGGE, for a period of at least 15 years and not exceeding 75 years. Generating is subject to centralized planning, with licenses for new electricity suppliers awarded by public tender.

The **binding generation** licenses will be revoked with the expiry of the PPAs, being a Non-binding license granted in exchange.
Access to **NBES electricity generation** activity is granted by DGGE through the issue of a non-binding generating license. The non-binding generator is not obliged to supply electricity to NBES.
The distribution and transport activities in PES are under a monopoly regime, being subject to regulation.

In Mainland Portugal the electricity distribution business is carried out by EDP Distribuição through an open-ended binding license for the distribution of Medium and High voltage and through concession contracts with Municipalities. In accordance with specific legislation, Municipalities (Decree-Law nº. 344-B/82), have the right to distribute low voltage electricity. These contracts are established for a 20 years period, with the payment of a rental fee.

4 Actor analysis identifying technology carriers

Organisation	Interest	Influence & Power	Technical Capabilities	Awareness of Technology	Access to Technology	Knowledge How to Use Technology
EDP Distribuição	Yes	No	Yes	Yes	No	No
TESI	Yes	Yes	Yes	Yes	Yes	Yes
Air Liquide	Yes	Yes	Yes	Yes	Yes	Yes
Bascol	Yes	No	Partly	Yes	No	No
EDP	Yes	No	Yes	Yes	No	No
REN	Partly	No	Yes	Partly	No	No
DGEG	Partly	Yes	Yes	Partly	No	No
ERSE	Partly	Yes	Yes	Partly	No	No

5 Developing the Market Development Plan

There are two major obstacles related with the preparation of the market development plan. On one hand, there is a lack of general information about the new technology involved in this project, and on the other hand the very high costs of the technology.

In the first meeting with Bascol it was possible to realise about their lack of awareness about the fuel cells and how they work. The project was presented as well as an overview about the FC potential in buildings. They become very interested in this technology especially because of environmental issues.

However, as it was predictable, the price is the major issue. When they realized about the costs involved with this kind of technology, they seemed reluctant and asked if there are governmental or EU financial incentives and legislation available. Besides these barriers, they are still interested in collaborating with the project, because of a green image.

Another issue is related to the fact that there is not yet “excess” wind energy, by the time being. Once the necessary energy to produce hydrogen has to be bought from the only energy supplier existent in Portugal, the EDP Distribuição which is part of the EDP Group, the costs can increase even more.

Regarding the technology, the majority of the fuel cell manufacturers that were contacted are very reluctant to offer fuel cells for the residential sector with competitive prices . In the low to medium power range they are focused in the automotive/transportation and back-up power applications or they produce high power fuel cells (above 100 kW range). As far as there is not a large demand for fuel cells, the manufacturers cannot decrease the production costs of the Technology, and fuel cells will remain very expensive. On the other hand, while the prices of the technology are high, the end-user is not going to switch from grid electricity to an immature expensive technology. Therefore, like the example in Japan shows, this technology needs financial incentives from the government to take off, to become more attractive for end-user. The questions however still remain: What will happen once the incentives are cancelled? Will the market be established by then? Hopefully the prices will have dropped significantly, allowing their purchase even in the absence of incentives. If the prices of electricity will increase fast in the future in Portugal, as the actual economic framework and fossil fuel prices sharply increase projections show, then FC technology may have room for a successful market development.

In order to make possible the implementation of a fuel cell market there are some efforts to be carried out:

- There is a need for a great contribution of the government in the legal and financial fields. There has to be created new legislations regarding the application of fuel cells and with the hydrogen security (storage and transportation). In the financial field there has to be created some financial incentive programmes to support the investments in new energy production technologies such as fuel cells, in order to make the investment more cost-effective for the end user. The government support will depend on the successful demonstration of residential cogeneration pilot projects, worldwide.

- Some efforts to promote the project have to be made, explaining the technology involved and the advantages in its use, either close to the society and the building constructors, in order to eliminate the lack of information about hydrogen and fuel cells. Seminars and workshops organised in collaboration with Fuel cell manufacturers should be promoted by government institutions (DGGE, INETI, ….). Co-generation associations (Cogen Portugal), research centers, small energy consultancy companies, and the regional energy agencies, which have a key role in the energy economy development, should be involved. Informative leaflet brochures should be distributed among potential end-users, especially house owners and building constructors, and a to a broader extent, including distributed generation role in sustainability issues in the schools curricula's.

- There has to be made a joint effort of all the partners of the project, close to the manufactures of the RES-FC systems, in order to show them that the residential sector is a market with great potential and that they need to make an effort in order to reduce the price of the technology and to improve the lifetime, the reliability and the efficiency of the different elements of the system. Involving national fuel cell manufacturers in the dissemination activities, and preparing joint proposals to demonstrate the economic and environmental viability of micro generation projects with Fuel cells can be a way to move forward.