December 2006

7.0281 06GR-02

RES-FC Market
Status of regional markets
Final report

Gerard Kraaij
Marcel Weeda
ECN

Revision January 2008: Complete Revision

Revision April 2007: Extra info from DK; NL; PT; IC; DE

Revision March 2007: Extra info from DE; NL; PT; IC

Contents

List of figures

List of Tables

1 Introduction

The EU-project "RES-FC Market" aims to define market conditions and identify opportunities to accelerate the introduction of fuel cell household systems (FCHS) for cogeneration of heat and power (CHP) that use energy carriers from renewable energy sources (RES). This concept may help reduce CO_2 and other emissions related to energy use in households. For the market development it is essential that initial customers are identified and that by application of the FCHS the cost of the system decreases. The main objective of the project is to identify an aggregated market of 3000 RES-FCHS units to be realised in the near future. To this end 10 markets in 7 regions will be investigated that have been identified upfront as potentially interesting. "RES-FC Market" aims to accelerate the development and rate of cost reduction of FCHS by combining the initiatives and opportunities in various regional markets so that enough market pull will be generated to get FCHS developers to start producing systems in series.

This report concerns work package (WP) 2 of the project. Main objective of the work package is data gathering on technology performance and market characteristics including the supply, amount and cost of the RES. The information and results from WP2 will be used in WP3 for designing a market development plan which will be aimed at solving identified barriers for application of RES-FCHS. WP4 will be elaborated in parallel with WP3 and will address the economy of RES-FCHS by looking at the synergies from the aggregated market.

WP2 is divided in two parts:

1. State-of-the-art of RES-FCHS technology
2. Describing potential regional markets

The report from the first part “RES-FC Market; status and cost of the technology options” [1] describes the state-of-the-art of the renewable energy technologies, the hydrogen production techniques using these renewable energy sources and the fuel cell based CHP units considered in the project.

This report concerns the second part of WP2 and describes the status of 10 potential markets in 7 regions in Jutland (Denmark), Schleswig Holstein and Baden-Württemberg (Germany), Reykjavík area (Iceland), Coimbra region (Portugal), Navarra and Basque (Spain) and North Friesland (the Netherlands) for the conversion of RES into hydrogen for household fuel cell (FC) applications.

Chapter 2 provides a description of the RES-FCHS energy system concepts considered. Furthermore, the approach is described to characterise the 10 predefined regional markets.

Chapter 3 presents the results of the regional market characterisation. Issues addressed are:

- Characteristics of the regions.
- The energy system.
- The legislation and regulations.
- The renewable energy supply situation.
- The price and subsidy structure.
- Barriers for the market

Chapter 4 provides a first qualitative assessment of the market conditions for RES-FCHS present in the predefined regions based on the information gathered in Chapter 3. A more detailed assessment will be part of WP3 where regional development plans will be made. The purpose of the development plans is to describe how the barriers can be alleviated involving stakeholders. Improving the market conditions by sharing know-how on regional framework conditions and aggregating the market for cost reduction are the objectives for WP4. Further improvement of market conditions by technical improvements of the fuel cell system, leading to cost reductions is the aim of WP5.

2 Energy system description and approach for market characterisation

This chapter describes the fuel cell household system and the RES-FC Market energy system concepts, including the renewable energy sources considered for supply of fuel for the FCHS. Furthermore the chapter describes the market parameters required for an assessment of the opportunities for application of the RES-FC Market energy system concepts, and the method of data collection.

2.1 Fuel Cell Household System

In the first project meeting the outline for the fuel cell CHP system has been defined. To be able to benefit as much as possible from the economy of scale of an aggregated market, only a single type of FCHS has been decided upon. The system chosen is a PEM fuel cell based CHP unit for a single household with a power output comparable to the average electric power demand of the household. The system will use hydrogen as fuel, as hydrogen is a flexible and universal intermediate form of energy able to link various sources of renewable energy with the FCHS.

The following specification for the fuel cell CHP system is considered:

Electrical power:	0.5-1 kW_e
Fuel cell type:	PEMFC
Fuel type:	pure Hydrogen
Heating power:	0.5-1 kW_e
Operating temperature:	70-80°C

The system will have an electrical and heating capacity in the range of 0.5 - 1 kW. The exact size of the FCHS needs to be determined in a later stage on the basis of a more detailed analysis involving specific household energy demands and economic parameters. The system is most suited for new houses that have a low heat demand. One such example that will be investigated in WP4 is the passive house that requires less than 15 kWh/m^2 for space heating.

The existing natural gas grid is not suitable for transport and distribution of hydrogen because of material properties of the grid. The adjustment or renewal of existing gas infrastructure is costly. Therefore only new houses are assumed to offer a market for the application of the energy systems considered. An additional advantage of new houses is that, in contrast to existing houses, the heat to power ratio of the energy demand in this market sector generally compares reasonably well with the heat to power ratio from fuel cell systems. For the analysis passive houses are considered that have a space heating demand < 15 $kWh/m^2/yr$.

A hydrogen fuelled fuel cell based CHP system produces about the same amount of heat and electricity in terms of energy. In existing houses in the Northern countries, due to insufficient insulation, usually the heat demand is much larger than the electricity demand. This means that if all heat is produced in CHP mode (heat demand controlled operation), much more electricity is produced than can be used in the house. The excess electricity has to be delivered to the grid, requiring adequate feed-in tariffs to ensure economic viability. If only as much electricity is produced as necessary then not enough heat will be produced. The remaining part of the heat needs to be produced by burning gas, which does not benefit from the potential efficiency gain of CHP operation.

This is an additional reason for applying the FCHS in new houses. For Spain and Portugal the heat demand is low, requiring further elaboration of the potential in WP 3 and 4.

2.2 Renewable energy sources

The basic idea behind the RES-FC market project is to describe the development potential of residential cogeneration using hydrogen in order to increase the possibilities for implementation of renewable energy into the energy system, especially from intermittent sources, and to provide an additional way to supply households with renewable energy. The following primary renewable energy sources are considered in the project:

I. Organic matter suitable for biogas production via digestion
II. Biomass in general (suitable for gasification)
III. Wind Energy, especially “excess wind”

Three concepts for use of these renewable energy sources have been suggested. The concepts are listed below as Case 1 to Case 3. For each case the regions are mentioned that have been identified upfront as potentially interesting for implementation of these concepts:

Case 1: Biogas to CHP (see chapter 2.2.1)
- The region of Jutland, Denmark.
- The region of Baden-Württemberg, Germany.

Case 2: Biomass and Wind to CHP (see chapter 2.2.2)
- The region of Jutland, Denmark.
- The region of Baden-Württemberg, Germany.
- The region of Reykjavik, Iceland.

Case 3: Only wind to CHP (see chapter 2.2.3)
- The region of Jutland, Denmark.
- The region of Schleswig-Holstein, Germany.
- The region of North Friesland, the Netherlands.
- The region of Navarra, Spain.
- The region of Coimbra, Portugal.

Figure 1 to Figure 3 present a schematic overview of the concepts and the components therein.

2.2.1 Case 1: Biogas to CHP.

The 'Biogas to CHP' concept is shown in Figure 1. Biogas is produced in a biogas plant converting organic matter (manure) into biogas. The biogas is cleaned/upgraded to natural gas standard and mixed into the existing NG-Grid. The biogas/natural gas is transported by the existing natural gas grid to a region containing say minimum 300 households that are equipped with fuel cell systems for combined heat and power supply. The natural gas/biogas is reformed to pure H_2 at a central reforming station located close to a cluster of households. The hydrogen is transported from the reformer station to the household through a hydrogen grid. The hydrogen is converted to heat and electricity by a fuel cell CHP in the household.[1]

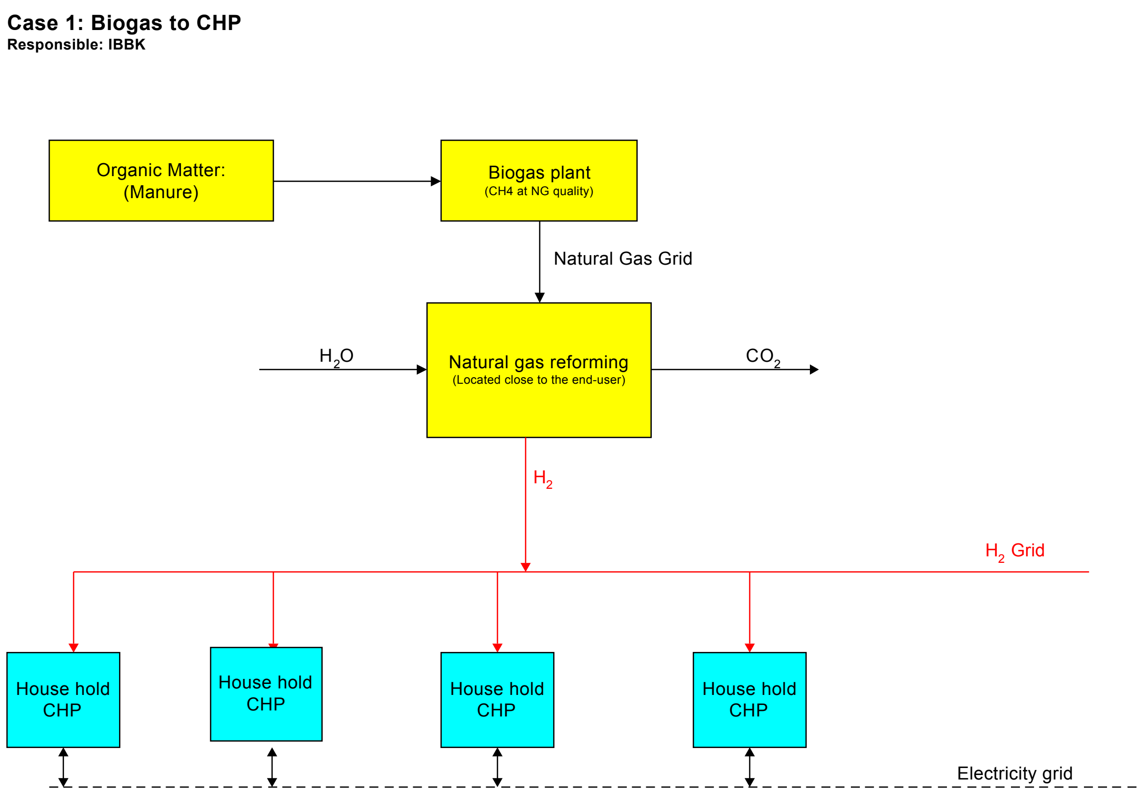


Figure 1: Case 1 Biogas to CHP

2.2.2 Case 2: Biomass and Wind to CHP

The 'Biomass and Wind to CHP' concept is illustrated by Figure 2. Methanol and ethanol are produced in a plant converting biomass and electricity into methanol and ethanol. The ethanol is produced by fermentation of biomass. The by-product from the fermentation, which is called the non-fermentable, is gasified with pure O_2 into a mixture of H_2, CO and CO_2. An electrolyser unit delivers the O_2[2]. Hydrogen

[1] In Europe some Sulphur containing compounds are added to the natural gas grid, in order to be able to smell any leakages. This sulphur will most likely deactivate the catalyst used for natural gas reforming, and hence it has to be removed prior to the reforming of natural gas into hydrogen.

[2] The electrolyser is assumed to operate almost constantly, but will be closed down in the peak hours where the electricity is most expensive. The electrolyser may be used to regulate the electricity grid, and offering a way to integrate/implement more fluctuating renewable energy sources such as wind power in the electricity grid.

from the electrolyser is mixed with the syngas leaving the gasifier. The gas mixture is used to produce methanol, which is stored as a liquid under normal conditions. The methanol is transported by truck to a local storage and reformer station located close to the cluster of households that are equipped with fuel cell systems for combined heat and power supply. The methanol is reformed to pure H_2. The hydrogen is transported from the reformer station to the household through a hydrogen grid. The hydrogen is converted to heat and electricity by a fuel cell CHP in the household.

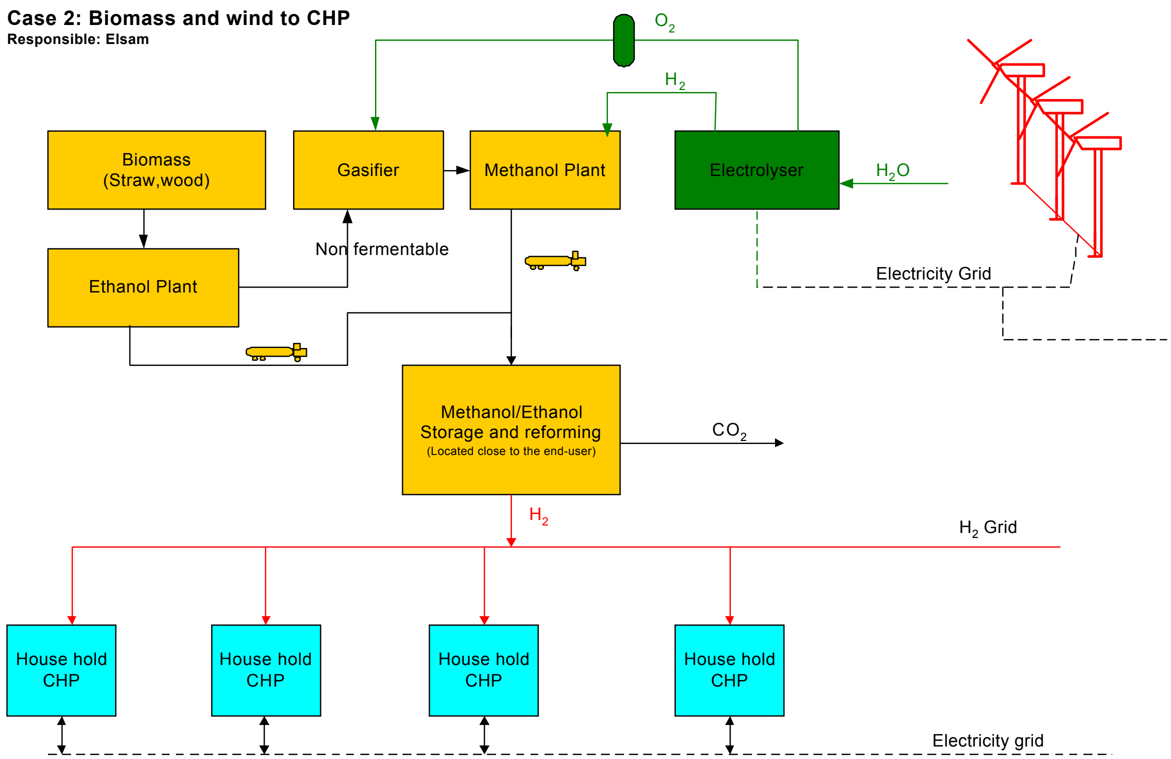


Figure 2: Case 2 Biomass and wind to CHP

2.2.3 Case 3: Only wind to CHP

The 'Only wind to CHP' concept is shown in Figure 3. Hydrogen is produced from electricity, through an electrolyser unit, located close to a cluster of households that are equipped with fuel cell systems for combined heat and power supply. The electrolyser may be used to regulate the electricity grid, and give room for more fluctuating renewable energy as wind power. The operational characteristics of the electrolyser will be established in WP4 for optimum economic benefits. The size and type of the hydrogen storage need to be discussed (daily / weekly storage). The electrolyser and the fuel cell are not supposed to operate at the same time since that would convert 2/3 of the electrical energy instantaneously into heat. The produced hydrogen is stored in a hydrogen storage located close to the electrolyser. The hydrogen is transported through a hydrogen grid from the hydrogen storage to the households. The hydrogen is converted to heat and electricity by a fuel cell CHP in the household.

Case 3: Only wind to CHP
Responsible: CENER

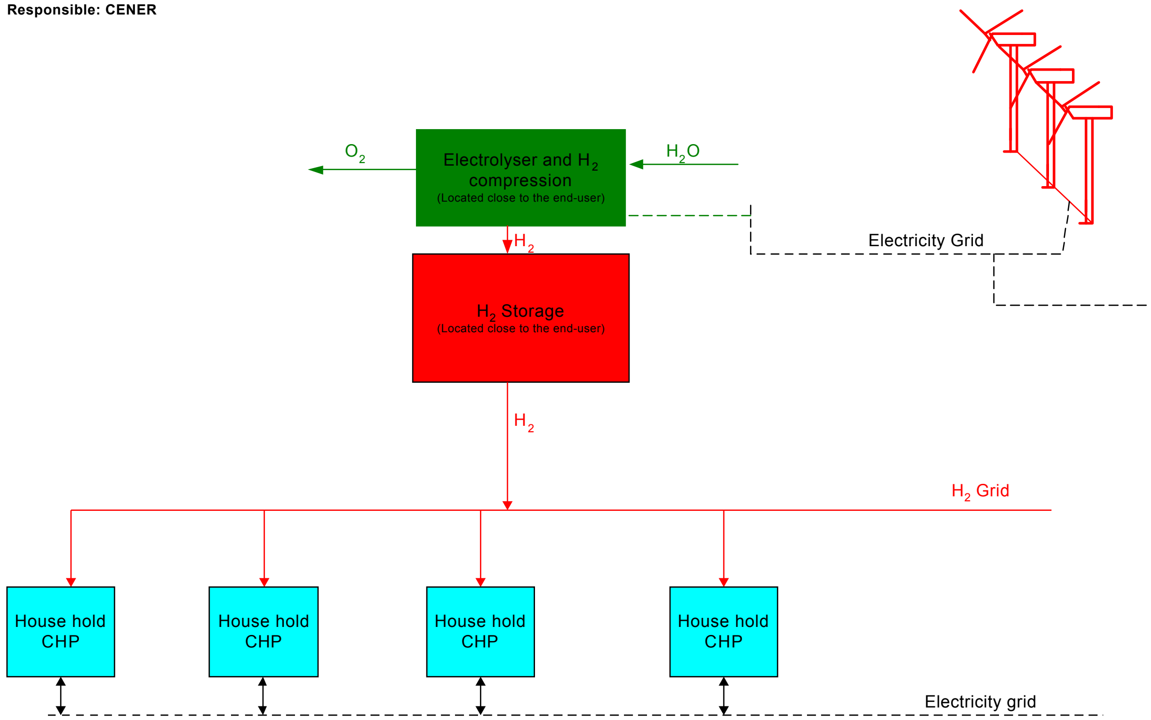


Figure 3: Case 3 Only wind to CHP.

2.3 Approach regional market description and information gathering

Chapter 3 describes 10 predefined regional markets, providing input for the activities in WP 3 and in WP4. WP3 is concerned with drawing up market development plans for the RES-FC Market concepts. WP4 is concerned with the evaluation of the feasible cost reduction as a result of producing a large number of systems for an aggregated market, and the cost gap that needs to be bridged to obtain an economically viable system.

For defining a market development plan in WP3 it should be clear what the current market conditions are related to the RES-FC Market energy system concepts, what the current opportunities are, and what the size of the market is. To this end information is required on:

- The number of new houses built each year. Adjustment or renewal of existing gas infrastructure is costly. Therefore only new houses are assumed to offer a market for the application of the RES-FC Market energy system concepts that involve a local hydrogen grid.
- Type, cost and amount of renewable energy installed and targets for implementation of RES.
- Regulation for small-scale residential CHP and the use of hydrogen.
- Feed-in tariffs for small-scale generators and policy support for renewable energy options.
- Present plans and targets for FCHS and stakeholders.
- Main barriers for application of FCHS, including developments on competing RES based systems for the supply of energy to households.

To be able to determine and evaluate in WP4 the cost gap that needs to be bridged to obtain an economically viable FCHS it should be clear how the total cost of the energy services (heat and electricity) provided by the RES-FC Market energy system concepts compare with the cost of the reference system. To this end chapter 3 includes information on:

- Current energy system for supply of heat and electricity to households.
- Heat and electricity demands in households
- Cost of heat and electricity

The latter issues are treated first in the description of the regional markets. To gather the required information on the regional markets the project partners representing these regions have been asked to fill in a questionnaire on the issues mentioned above.

3 Characterisation of the regional market

In this chapter the characteristics of the regions, its energy system, the regulations, the renewable energy supply and the price and subsidy structure are described, This serves as input for the market development plan of work package 3 and the economical assessment of the aggregated market in work package 4.

3.1 The region of Jutland, Denmark

3.1.1 Description of the region of Jutland

Jutland is the western continental part of Denmark and shown as the red area on the map. Denmark's market economy features very efficient agriculture, up-to-date small-scale and corporate industry, extensive government welfare measures, very high living standards, a stable currency, and high dependence on foreign trade. Denmark is a net exporter of food and energy and has a comfortable balance of payments surplus and zero net foreign debt. The next tables are for Denmark as a whole. Whenever specific information for Jutland is available this will be provided.

Table 1: Characteristics on houses and inhabitants for Denmark and Jutland.

Characteristics	Denmark	Jutland
Inhabitants (*1000)	5500	2513
Houses (*1000)	2429	1110*
Inhabitants/km^2	127	84
New/existing houses (%/yr)		

* Estimate based on the area's share of the population.

Demographically and geographically, the area of Jutland is characterised by a relatively low population and a by Danish standards relatively large area resulting in a region with a modest population density. The region is also characterised by good wind resources and farming thereby creating good settings for local energy production this being based on bio resources as well as on wind power.

3.1.2 Energy infrastructure for heat and electricity

Table 2 describes the connections of the household to the public grids. Nearly all houses in Denmark are connected to the electric grid and a very large share is also connected to either district heating grids or to a nationwide natural gas grid. In spite of the low population density in some areas, natural gas come in third place after renewable energy and district heating for house heating in Denmark. District heating is used extensively throughout the country in all large cities and in very many small towns down to sizes of a few hundred dwellings. This has in fact been one of the consequences of a post oil-crisis Danish policy of having house heating supplied via grids. This has removed much of the fuel decision power from individual consumers to the operators of district heating systems and the natural gas companies.

Table 2: Energy distribution infrastructure to houses in the Denmark

Energy infrastructure to houses	Denmark
Electricity grid	99.99%
Natural gas grid	Covers large part of the country
District heating grid	60%

3.1.3 Household energy system demand

Table 33 presents figures for the energy consumption in Danish households. Being in a temperate climate, Denmark has a reasonable high energy consumption for space heating though progressively stricter buildings codes have tried to reduce the specific demand over the last decades. Electricity consumption is also relatively high dues to a high standard of living and many electrical appliances per consumer.

Table 3: Energy consumption of households in Denmark

Consumption patterns for households	Denmark Average household	Unit
Electricity consumption	4000-4500	kWh/yr
Energy consumption for space heating	5333	kWh/yr
Energy consumption for tap water	3500	kWh/yr
Energy consumption for cooking	n.a.	kWh/yr

3.1.4 Household cost for heat and electricity

Table 4 gives an overview of the average energy prices for Danish household in 2007.

Table 4: Energy prices including taxes for households in Denmark

Energy prices for households	Denmark	Unit
Electricity price (Eurostat 2007)	0.258	€/kWh
Natural gas price (Eurostat 2007)	0.111	€/kWh
Energy price for space heating	0.057	€/kWh
Energy price for tap water	0.057	€/kWh

The thermal capacity in Western Denmark includes 3400 MW on central CHP plants that can operate in a condensing mode and are mainly run on coal. Besides, the system includes a total capacity of 1593 MW of small-scale CHP power plants distributed over smaller towns and villages. These plants mainly operate on natural gas, biomass, and some biogas. Around 60% of the local population is connected to CHP. The heat price however varies from town to town. In larger urban areas with coal plants, the heat is cheaper than in areas with gas-fired engines, which is where the RES-FC can have a larger potential.

3.1.5 Feed-in tariff and subsidies

Table 5 gives an overview of the average feed-in tariff and subsidies for renewable energy in Denmark.

Table 5: Overview of feed-in tariff and subsidies for renewable energy in Denmark.

Renewable energy option	Tariff/subsidy	Unit
Electricity feed-in tariffs	none	€/kWh
Subsidy electricity from wind energy	0.0134	€/kWh
Subsidy electricity from biomass		€/kWh

Subsidy electricity from biogas	0.08 (fixed price)	€/kWh
EU subsidy for cultivation of energy plants on set-aside lands	45	€/ha

Unfortunately, in Denmark there are no feed-in-tariffs while producing or using electricity from bio resources. There have previously been feed-in tariffs but in a move to curb expenses removed this tariff and replaced it by a small addition to whatever the plant can get on the spot market. The system guarantees a minimum price for electricity production but is complex as the it is different for different technologies and has a decline in minimum costs based on either age or full-load hours of operation.

3.1.6 Regulations for small-scale CHP and hydrogen

The following observations regarding regulations a made:

- Research grants are available on "H_2 Strategy for Research, Development, and Demonstration" published by the Danish Energy Authority
- No specific H_2 legislation, yet support for new renewable technologies other than wind.

3.1.6.1 Biogas

The Danish legislation on gas quality reflects the present natural gas quality, which excludes biogas from the natural gas network [4]. Table 6 compares the natural gas and biogas composition, physical properties, and combustion key numbers [4]

The natural gas grid covers almost all Denmark; usage biogas in natural gas pipeline system would open significant market for biogas. In order to achieve it, increasing of Wobbe index of biogas is necessary, which is equal to upgrading the biogas. The upgraded biogas is called biomethane or SNG (Substitute Natural Gas). To accomplish Danish legislation on gas quality the Wobbe index should be in range of 51.9 – 54.9 MJ/m3n, the relative density less than 0.7, and methane content at least 98.4% (the rest CO2) [4,5]. Furthermore, maximal amount of sulphur compounds as well as required concentration of odorants is depicted in Table 6 and Table 7, respectively [4].

Table 6: Maximal amounts of sulphur compounds

	Biogas mg/Nm^3	**Natural Gas** mg/Nm^3
H2S	<7	<5
Other sulphur compounds	< 10	< 10

Table 7: Required amount of odorants in gas

Odorant concentration	**Biogas** mg/Nm^3	**Natural Gas** mg/Nm^3
THT	16.0	10.5
Mercaptan	6.0	4.0

According to [4] if biogas is upgraded to 90% methane, then a mixture of 25% biogas and 75% natural gas will have a Wobbe index within the required range. Without upgrading biogas, 8% of it (65% methane) can be present in the mixture.

3.1.7 Supply of renewables

3.1.7.1 Biogas supply and installation

Right now in Jutland exist 14 joint biogas plants and 52 farm scale biogas plants. In the whole Denmark there are 20 joint and 57 farm scale biogas plants, respectively. In 2003 they were utilizing 1.742.156 tons of manure and 450.705 tons of organic residues, which gives 2.192.864 tons of wastes utilized via anaerobic digestion process. Figure 4 shows existing biogas plants in Denmark.

Within the next 5 years or before end of 2010 it is planned to establish around 10 new biogas plants in Jutland. 2 of them in the south (Tønder and Als), 3 in the region of Vejle County, 2 in Norddjurs and Syddjurs, and the rest in Holstebro, Viborg, Morsø, and Nothern Jutland.
More biogas plants are planned to be built till 2020 as stipulated from the Danish Energy Agency forecast, at least a doubling of the capacity of 2010 [6].

There are three main resources for anaerobic digestion process:

1. Manure – amount of total manure in 1993 was equal to 44mill tons/year
2. Industrial organic waste – amount of it is app. 0.5-0.7 mill tons/year
3. Energy crops – maize crop - Maize silage – in 2002 the area for cropping the maize was equal to 96000ha. Nearly all maize grown in Denmark is harvested for maize silage. The concentration of maize fields is the largest in the western South Jutland and northern part of Central Jutland, where up 25% of the agricultural area is dedicated to maize [2].

The cost of the fuel for the biogas is expected to consist only of the transportation costs of the maize and manure and is estimated as 0.16 €/km/m^3.

Figure 4: • 20 joint biogas plants ; • 57 farm scale biogas plants

3.1.7.2 Ethanol/Methanol supply

Bio-ethanol is traded on the world market, and can be purchased and delivered at any place in Denmark. As a consequence the production of bio-ethanol is not a barrier for an FC-market, even if there will be no bio-ethanol production in Denmark. However, there have been several projects regarding construction of ethanol plants in Denmark, both in the southern part of Jutland, and latest on the island of Bornholm. The proposed plant on Bornholm is a second generation ethanol plant based on residual products from the agriculture. In any case a bio-ethanol plant will have a much higher production than what can be consumed by a cluster of say 300 FC-units.

Methanol is mainly produced from natural gas, in regions of the world where the natural gas else will be flared. At Schwartze Pumpe methanol is produced from waste in a gasification process, hence it will be possible to purchase renewable methanol.

It will in all cases be necessary to reform the ethanol/methanol or biogas into hydrogen, before it is distributed in the hydrogen grid to the single household FC. Reformation of methanol into hydrogen is much simpler than reformation of ethanol, and small-scale methanol reformers are commercial available.

The cost of straw used as biomass for the ethanol production process of Figure 2 is 0.0168 €/kWh delivered at the factory.

Methanol can be purchased for around 145 USD/Metric Ton (=5.9 €/GJ) at the world market, and a suitable methanol reformer (cracker) for around 2.000.000 Euro

Optimistic Case

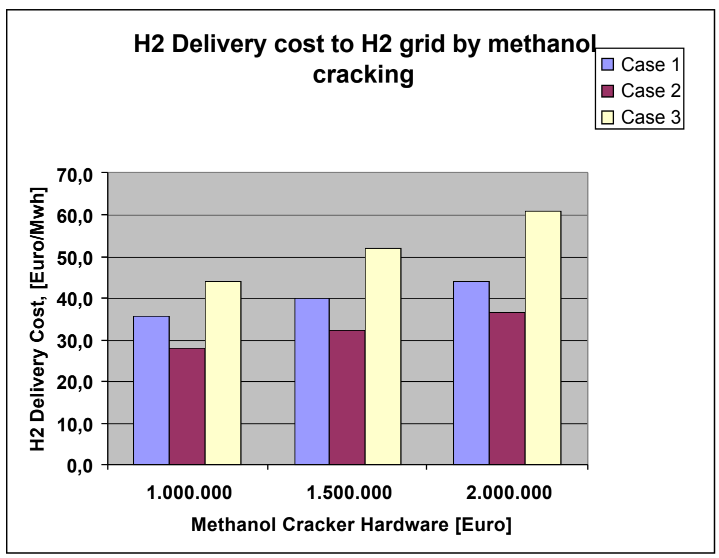
Assumption	Case 1			
Methanol price	145 usd /ton = 5.9 Euro / GJ			
Availability	90%			
IRR	2% !!!			
Methanol cracker hardware	Euro	1.000.000	1.500.000	2.000.000
H2 delivery cost	Euro/GJ	9,9	11,1	12,3
H2 delivery cost	Euro/Mwh	35,6	40,0	44,1

Optimistic Case

Assumption	Case 2			
Methanol price	100 usd /ton = 4 Euro / GJ			
Availability	90%			
IRR	2% !!!			
Methanol cracker hardware	Euro	1.000.000	1.500.000	2.000.000
H2 delivery cost	Euro/GJ	7,8	9,0	10,2
H2 delivery cost	Euro/Mwh	28,1	32,4	36,5

Realistic Case

Assumption	Case 3			
Methanol price	145 usd /ton = 5.9 Euro / GJ			
Availability	70%			
IRR	6% !!!			
Methanol cracker hardware	Euro	1.000.000	1.500.000	2.000.000
H2 delivery cost	Euro/GJ	12,2	14,5	16,9
H2 delivery cost	Euro/Mwh	43,9	52,2	60,8



Project Horizon	Years	20
Project Discount Rate	%	6,0
Interest During Construction	%	5,0
Global Inflation Rate	%	2,0

Hydrogen from cracked methanol can be delivered to the hydrogen grid for around 30-60 Euro/MWh.

3.1.7.3 Wind energy supply/installations

In 2004, wind energy provided 32% of the electricity consumption in Western Denmark. The installed capacity stayed practically constant over the last 4 years. In 2006, the total installed wind turbine capacity is 3140 MW, of which 213 MW is offshore. This compares to an electricity consumption that varies between 1,150 MW and 3,800 MW. With high wind velocities, wind power production can exceed the local electricity demand. Moreover, the changing wind velocity gives rise to a great need of fast reserve capacity to regulate the power imbalances. The typical onshore wind production duration curve is given in Figure 5.

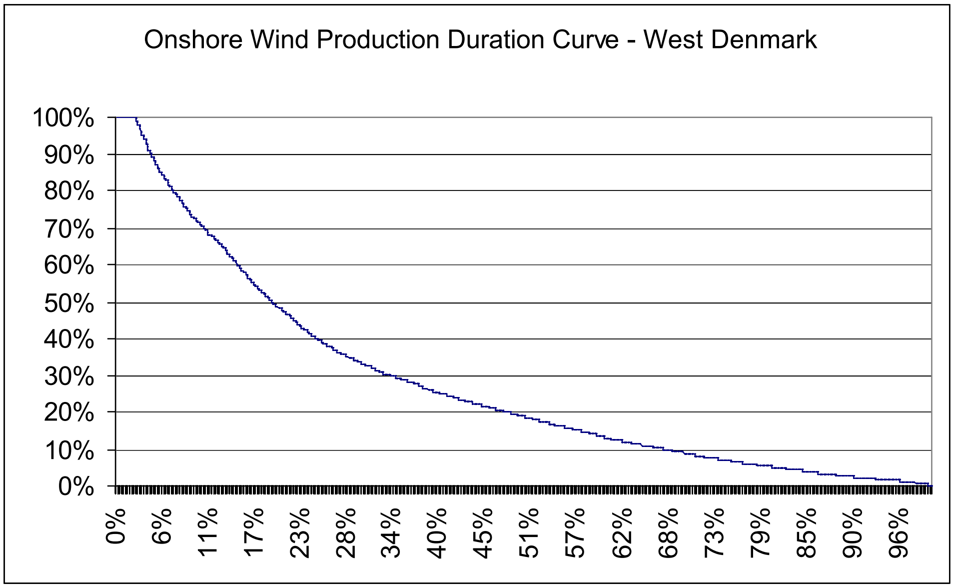


Figure 5: Typical wind electricity production curve for Denmark

The cost of off-peak electricity that can be used for the electrolyser is estimated as 0.062 €/kWh.

3.1.8 Present plans for FCHS and key actors

The "Herning" project.
The "Herning" project is about establishing 200 CHPs using hydrogen produced on RES (wind power). The overall scientific and technological objectives of the project are to promote innovative sustainable energy communities through innovative demonstration.

The innovative elements are connected to:

- The technologies applied at the local level in Herning Municipality (DK), demonstrating integration of a renewable energy source (RES), wind energy, through production of H_2 distributed in a local H_2-gasnet to 200 houses, where the H_2-gas is used in fuel cell/combined heat and power (CHP) systems for electricity and heat production.
- Utilization of "excess wind electricity" in an electrolysis plant for producing H2 to be sent through a H2-gasgrid to be used in low temperature PEM fuel cell/CHP micro system for CHP production in 200 private households
- The electrolysis system will be supplemented with a filling station, so the H_2 produced also can be used for sustainable transportation and to make the use of the produced H_2 more flexible, which is necessary for the economy of the system
- This demonstration element is the second of its kind in EU, after Fruehøjgård, with demonstration of large scale-integration of RES into the energy system using H_2 as the energy carrier and fuel cell/CHP systems for use of the H_2. See more about the vision on www.H2PIA.com
- The regional demonstration and promotion project will further comprise macro (towns - districts) and micro (households) levels including the elements of:
    - Heating distribution systems
    - CHPs using RES
    - Rational use of energy in district heating distribution

- Rational use of energy in heating end-use in buildings

3.1.8.1 Present plans outside Jutland

The "Sonderborg and Nakskov" project.
Sonderborg lies in Jutland and Nakskov in Region Sjælland.
Eight Danish companies with complementary interests are co-operating on a three-phased project on demonstrating µCHP based on Danish fuel cells.
The three phases, following each other, begin with prototypes of different µCHP units and end up in demonstrating 100 “close to commercial” µCHP fuel cell units at “real end users”.

- Phase 1 - µCHP prototypes, α-test and improvements of sub-components;
- Phase 2 - Demonstration of prototypes at “professional users” (β-test);
- Phase 3 - 100 demonstration units at “real end users”.

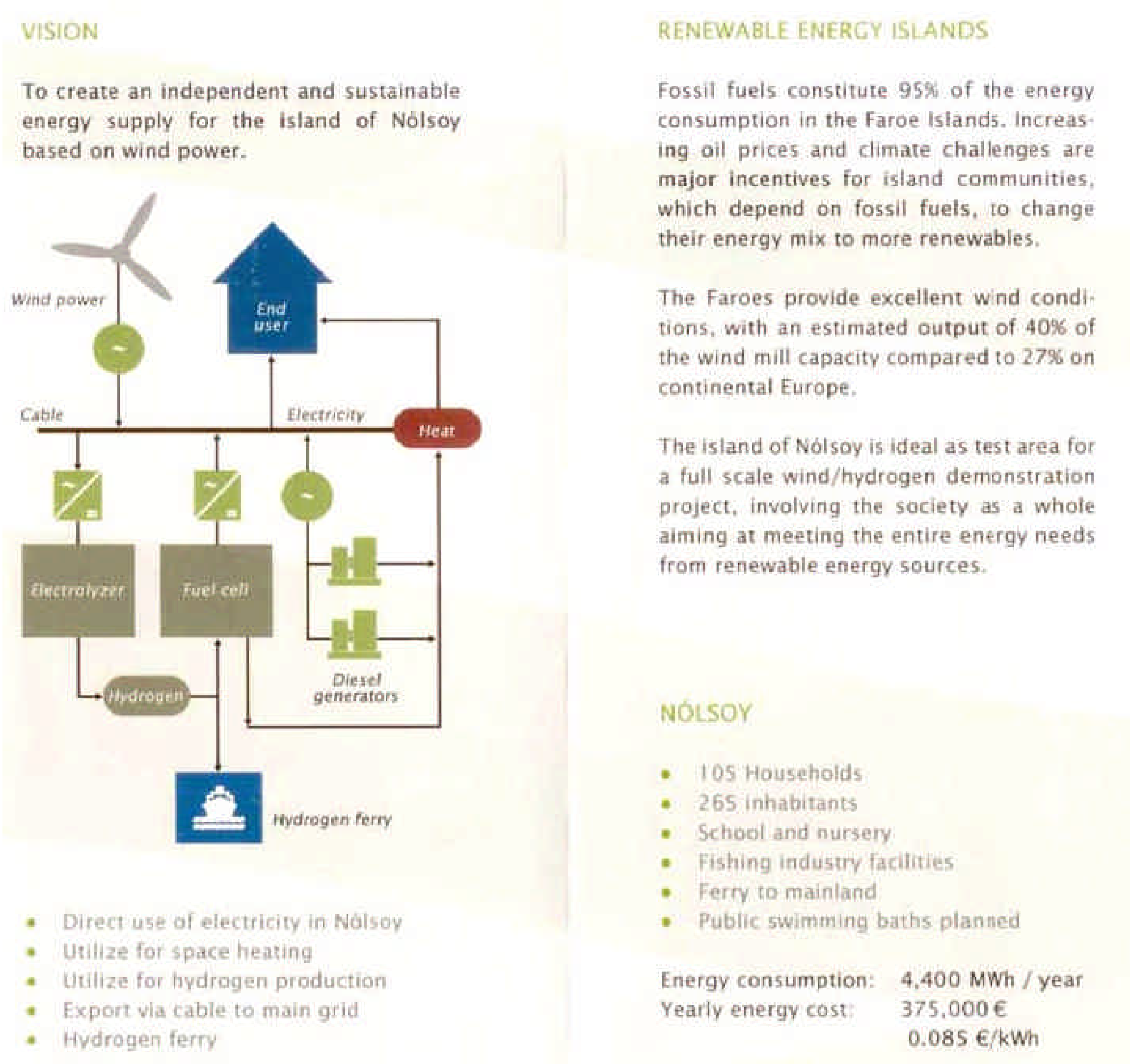
Phase 2
Based on the experience from Phase 1 and on the research carried out in the companies, β-type µCHP units will be designed, implemented and tested during Phase 2. The 10 to 15 units in the β-test will include the following combinations:

- LT-PEMFC units fuelled with H2;
- HT-PEMFC units with reformer;
- SOFC units with catalytic partial oxidation;
- SOFC units with reformer.

The β-test units are developed, produced, installed and tested. The tests will in phase 2 be conducted by energy distributing companies around the cities Sonderborg and Nakskov. The test hosts will ensure that the units run and are serviced, and that the experience is transferred to Phase 3 of the project.

Phase 3
Before µCHP systems can be sold on “close to commercial” terms, it will be important to get experience from a certain number of reference systems at “real end-users”. By establishing approx. 100 systems, experience in installation, operation, maintenance and end-user satisfaction will be obtained. At the same time, a necessary statistical confidence is established before deciding on an actual production. In phase 3, focus will be on the continued technical development of the fuel cell system and the mass production possibilities. The test setup of the 100 µCHP units will be remotely controlled. In part of the test the units will be operated as a virtual power plant.

The Nolsoy Project at the Faroe Islands has the ability for 105 households; see Figure 6. The community is interested in creating an independent and sustainable energy supply system.



VISION

To create an independent and sustainable energy supply for the island of Nólsoy based on wind power.

- Direct use of electricity in Nólsoy
- Utilize for space heating
- Utilize for hydrogen production
- Export via cable to main grid
- Hydrogen ferry

RENEWABLE ENERGY ISLANDS

Fossil fuels constitute 95% of the energy consumption in the Faroe Islands. Increasing oil prices and climate challenges are major incentives for island communities, which depend on fossil fuels, to change their energy mix to more renewables.

The Faroes provide excellent wind conditions, with an estimated output of 40% of the wind mill capacity compared to 27% on continental Europe.

The island of Nólsoy is ideal as test area for a full scale wind/hydrogen demonstration project, involving the society as a whole aiming at meeting the entire energy needs from renewable energy sources.

NÓLSOY

- 105 Households
- 265 inhabitants
- School and nursery
- Fishing industry facilities
- Ferry to mainland
- Public swimming baths planned

Energy consumption: 4,400 MWh / year
Yearly energy cost: 375,000 €
0.085 €/kWh

Figure 6: The Nolsoy wind-hydrogen project at the Faroe Islands.

The key actors in Denmark are:
Municipalities of Herning, Sonderborg and Nakskov
Fuel cell industry

- IRD
- Dantherm
- Haldor Topsoe

Dong energy
HIRC

3.1.9 Main barriers

The barriers mentioned are:

- It is not economically to transport biogas for longer distance, due to its low-grade low-value as a fuel.
- The cost of the fuel cell and cost of the electrolyser are at this stage still too high.
- No ethanol reformers available on the market

3.1.10 Contacts

A contact list for electrolyser manufacturers is provided in [1].
Martin Møller, DONG Energy, power company.

3.2 The regions of Schleswig Holstein and Baden-Württemberg, Germany

3.2.1 Description of the regions

3.2.1.1 Region of Baden-Württemberg

Baden-Württemberg is situated in the south-western part of Germany as shown on the map. Although it has a few multinationals, Baden-Württemberg's economy is basically dominated by small and medium-sized enterprises. Many enterprises are considered innovative. Specific information on a settlement area where 300 new households are aggregated is not available. In Table 8 the characteristics on houses and inhabitants for Germany and the regions Schleswig Holstein and Baden-Württemberg are provided. Whenever specific information for Baden-Württemberg or Schleswig Holstein is available this will be provided.

3.2.1.2 Region of Schleswig Holstein

Schleswig Holstein is the northernmost federal state of Germany and is situated between Northern Sea and Baltic Sea as shown on the map. In contrast to Baden-Württemberg, Schleswig-Holstein is a structurally weak region with a relatively high proportion of its population working in agriculture – especially in the western part where tourism and wind energy also play an important role. Specific information on an aggregated settlement with a minimum number of 100 new households is not available.

Table 8: Characteristics on houses and inhabitants for Germany and the regions Schleswig Holstein and Baden-Württemberg.

Characteristics	Germany	Baden-Württemberg	Schleswig Holstein
Inhabitants (*1000) 2006	82315	10739	2834
Houses(apartments) (*1000) 2006	39754	4910	1380
Inhabitants/km^2	231	300	179
New/existing houses (%/yr)			

(Source: Statistisches Bundesamt, Statistisches Landesamt Baden-Württemberg)

3.2.2 Energy infrastructure for heat and electricity

In Germany there is no predominant fuel source and therefore the coverage rate of the various existing grid systems vary from region to region depending on their natural and industrial conditions (see Table 9).

Table 9: Energy distribution infrastructure to houses in the Germany

Energy infrastructure to houses	Germany
Electricity grid	99.99%
Natural gas grid	52 % of all households, 98% in areas connected to the gas grid
District heating grid	18.702 km (2003),

12 % of the households (2001)

The coverage rage of the electricity grid is very high and almost 100 % of all households are connected to it. Table 10 shows the total amount of electricity produced in 2005 in Germany, Baden-Württemberg and Schleswig-Holstein respectively with respect to the energy sources. For Schleswig-Holstein no official data for 2005 has been available at the time of writing. Therefore data from 2004 is provided.

A different picture arises when looking at the natural gas grid. Here only 52 % of all households in Germany are connected, but in some regions the connection rate can increase to 98 %. District heating grids mainly exist in areas close to big power plants and in densely populated areas, but with the increased conversion of biomass to energy smaller district heating systems start to be established. A less important grid for private households is the industrial hydrogen grid with a length of 100 km in Leuna and 240 km in the Ruhr valley. Both areas are in regions not considered in this project.

Table 10: Energy sources for the production of electricity in Germany.

Energy source	**Germany**		**Baden-Württemberg**		**Schleswig-Holstein (2004)**	
	TWh	**%**	**TWh**	**%**	**TWh**	**%**
Coal	288,5	46,6	21	29,2	4	12,1
Nuclear power	163	26,3	36	50,5	27	75,3
Natural gas	70	11,3	4	5,7	0,25	0,7
Mineral oils	11,5	1,9	-	-	0,03	0,1
Renewables	63	10,2	7	10	4	11,2
Others	22,8	3,7	3	4,5	0,2	0,6
Total	**618,8**	**100**	**71**	**100**	**35,48**	**100**

With respect to renewable energy sources Baden-Württemberg in 2006 produced approx. 12% (8.627 Mio. kWh) of its electricity with renewables. An estimated number of 480 biogas plants contributed with 5 % to the electricity produced from renewables. The vast majority of biogas plants operate in the agricultural sector, but local energy utilities as well as sewage treatment plants are also looking into this technology as means for producing green energy or green gas. Their primary interest in green gas is the injection into the local gas grid. It's utilisation in fuel cells is considered to be a future technology. In Germany approx. 700 regional companies and municipal utilities are operating local and regional natural gas grids. An example is Stadwerke Esslingen, the municipal utility of City of Esslingen that is located east of Stuttgart in Baden-Württemberg.

Stadtwerke Esslingen (SWE) is a municipal utilities company in central Baden-Wuerttemberg that supplies the City of Esslingen and a part of Esslingen district with water, natural gas and heat. In total SWE has 40.000 customers from private households and industries. They operate a natural gas grid with a total length 420 km. SWE is open towards the utilisation of renewable energies for supplying households. They for example started operating a heat supply station on wood chips in 2004. Also they have plans to operate a biogas plant and to feed the produced biogas into the natural gas grid. As municipal utilities company that already utilises renewable energies and considers the operation of a biogas plant SWE is a possible partner for promoting the use of household fuel cell systems and for applying 300 units. Specific information on a settlement area where 300 new households are aggregated is not available.

3.2.3 Household energy system demand

With respect to the application of household fuel cell systems with an electrical power of 1 kW the energy consumption (electricity and heat) of the households in the regional market are of interest. In Baden-Wuerttemberg, as well as in Germany in general, a continuous rise has been observed during the last ten years [UBA2009; STA07a]. According to STA07a the total electricity demand of all private households in Baden-Wuerttemberg increased from 2.859 Mio. kWh in 1965 to 19.687 Mio. kWh in 2004. Related to the population of Baden-Wuerttemberg this means that the electricity demand of each inhabitant has been rising from 361,5 kWh/ p in 1965 to 1.837 kWh/ p in 2004 (see Figure 7).

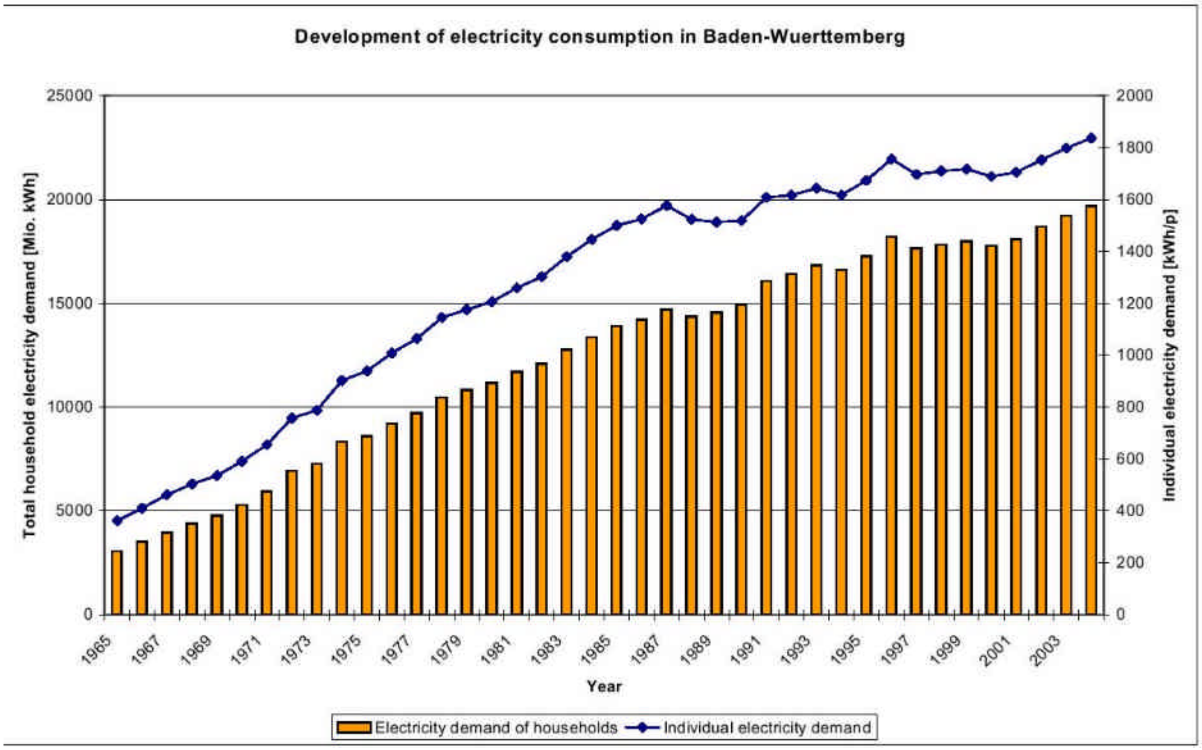


Figure 7: Development of electricity demand in Baden-Wuerttemberg (source: STA07)

The main reasons for this increase are a constantly growing population due to migration to Baden-Wuerttemberg, the growing numbers of single or two person households and the rising number of electrical equipment such as dishwashers, microwaves, laundry dryers, computers, etc. Although the electrical efficiency of domestic appliances has improved during the last years the positive effects are counterbalanced by the growing numbers of single households. According to the official statistical data of Baden-Wuerttemberg [STA07b] the population of Esslingen region will stay relatively constant until 2025 due to continuing net immigration. If there are no considerable improvements concerning the electric efficiency of domestic appliances the electricity demand will at least stay on the same level as today.

Table 11 presents figures for the energy consumption in German households based on a household with four persons.

Table 11: Energy consumption of households in Germany

Consumption patterns for households	Germany Average household	Unit
Electricity consumption	3500	kWh/yr
Energy consumption for space heating	20969	kWh/yr
Energy consumption for tap water	n.a.	kWh/yr

Energy consumption for cooking	n.a.	kWh/yr

3.2.4 Household cost for heat and electricity

In Germany various fossil and renewable fuels are utilised for heating and hot water production ranging from coal, oil and natural gas to wood, solar thermal systems, geothermal systems, etc.. Table 12 gives an overview of the average energy prices for German household in 2007. It is difficult to state a price for heating and hot water production. On national level natural gas is currently the number one choice as source for heating for newly constructed houses. In Baden-Württemberg for example 64 % of all new buildings use natural gas for heating, 12 % use oil and 24 % use other sources (e.g. renewable energy). According to data gained from building permits applied for in 2006 the share of other sources increases to 35,2 % whilst the use of natural gas decreases to 57,1 % and the use of oil to 7,8 %. The share of renewable energies will continue to rise as the State of Baden-Württemberg in 2007 passed a law stating that new residential houses (applying for a building permit after 1 August 2008) have to cover 20 % of their heat demand by renewable energies. Existing houses have to fulfil this requirement after 1 August 2010 when the heating system needs to be replaced. The price paid for natural gas by private households in 2005 in Baden-Württemberg was 0.045 €/kWh[3] which is higher than the average gas price of 0.036 €/kWh.

Table 12: Energy prices including taxes for households in Germany

Energy prices for households	Germany	Unit
Electricity price (Eurostat 2007)	0.195	€/kWh
Natural gas price (Eurostat 2007)	0.09	€/kWh
Energy price for space heating	Depends on source for heating	€/kWh
Energy price for tap water	Depends on source for heating	€/kWh

3.2.5 Feed-in tariff and subsidies

Electricity produced from fuel cells can be sold to the grid or the electricity supply company respectively. According to the “Kraft-Wärme-Kopplungsgesetz (KWKG)[4]” the grid owner is obligated to buy this electricity. The price paid for electricity from fuel cells depends on the fuel source and is composed of a basic tariff and several boni. If fossil fuels such as natural gas are used the KWKG is applied and the feed in tariff is composed of three components:

- the “common price” paid by the electricity supply company (according to the price paid for baseload power at the electricity stock market (EEX) in Leipzig, Germany)
- the fuel cell bonus of 5,11 ct/ kWh, which is paid over a period of ten years and
- the avoided charges for accessing the electricity grid (according to CHP systems are generally exempt from grid access charges).

The basis for calculating the feed in tariff changes, if renewable sources are used to fuel the fuel cell. Germany supports the production of electricity from renewable energy sources with the “Renewable Energy Sources Act” which was amended in 2004. According to this Act the utility has to pay producers of green electricity certain minimum feed-in tariffs, which have been defined in 2004. Additionally certain boni can be (must be) granted by the utility, if certain criteria are additionally met. For electricity produced from biomass the tariffs are as follows:

3 prices are excluding VAT
4 Federal Act on heat and power cogeneration

Table 13: Overview of feed-in tariff and subsidies for biomass in Germany.

El. Power installed	Minimum feed-in tariff [€/kWh]	Bonus for processing energy plants	Bonus for utilising the heat (CHP)	Bonus for applying innovative technology (only if heat is used)
Incl. 150 kWel	0.115	0.06 €/kWh electricity produced	0.02 €/kWh of utilised heat	0.02 €/kWh electricity produced
Incl. 500 kWel	0.099			
Incl. 5000 kWel	0.089			
> 5000 kWel	0.084			

Starting from January 1, 2005 those minimum tariffs decreased by 1,5 % per year which is the basis for calculating the actual tariff for the year in which the biogas plant starts operating. This minimum tariffs is, however, granted for 20 years starting from the year of commissioning. For 2007 the feed-in tariffs would therefore vary between 0.0802 €/kWh and 0.2098 €/kWh depending on the size and configuration of the plant.

Additional income for farmers could be generated from subsidies for setting aside land (300 € ha) and for cultivating energy crops on this land (45 €/ha). This regulation depends strongly on the EU policies for agriculture and thus might change from one year to the next.

For electricity produced from wind energy the feed-in tariffs are lower and is at least 0.055 €/kWh for on-shore windmills whereas off-shore windmills get at least 0.0619 €/kWh. Special boni are granted, if the efficiency is very high (highly efficient technology or repowering of on-shore windmills) or if the environmental conditions are difficult (off-shore windmills). Starting from January 1, 2007 for on-shore windmills and from January 1, 2008 for off-shore windmills respectively, the feed-in tariffs decrease by 2 % per year. Table 14 gives an overview of the average feed-in tariff and subsidies for renewable energy in Germany.

Table 14: Overview of feed-in tariff and subsidies for renewable energy in Germany.

Renewable energy option	Tariff/subsidy	Unit
Electricity feed-in tariffs	**Biogas**: 0.0816 ... 0.2116 **Wind**: on land: 0,0836 (decreasing to 0,0528) off shore:0,091 (decreasing to 0,0619)	€/kWh
Subsidy electricity from wind energy	n/a	€/kWh
Subsidy electricity from biomass	Premium for set-aside land (approx. 300 €/ha)	€/kWh
Subsidy electricity from biogas	n/a	€/kWh
EU subsidy for cultivation of energy plants on set-aside lands	45	€/ha

3.2.6 Regulations for small-scale CHP and hydrogen

In Germany several federal laws and regulations affect the installation and operation of fuel cells. The basic law that affects FC-systems directly is the KWKG (see above). It obligates electricity supply companies to buy electricity produced by CHP-systems at certain conditions. An exemplary set-up would be a fuel cell operated on natural gas. As soon as fuel comes from renewable sources the EEG (RESA) is applied instead. This would be the case if the fuel cell would be operated on upgraded biogas. In our scenario of operating small-scale FCHS on renewable energy sources the upgraded biogas would need to be transported to the households – or a central reformer respectively – using the natural gas grid.

Up to date (March 2007) Germany does not have a legislation that regulates the feeding-in of biogas into the natural gas grid. Nevertheless a couple projects already exist where refined biogas is fed into the natural gas grid and several other projects are currently being planned. The most popular examples are the Public Services of the City of Aachen and the R.E.S Renewable Energy Systems GmbH in Munich-Pliening, which started 2006 with feeding refined biogas into the natural gas grid. In all cases – regardless of their current status (implemented or planning status) – public services that own and operate the local natural gas grid are involved in the projects. This is also the case in the district of Esslingen near Stuttgart where the public services are currently thinking about feeding raw biogas into their NG-grid. In this way public services are building up their knowledge and competence in this sector without the need to deal with supra-regional regulations for feeding-in and conveying (refined) biogas. As public services often also own or operate sewerage treatment plants the knowledge they gain in those projects could contribute to a new paradigm for urban energy production and utilisation as public works in Germany are also discussing the possibilities of having sewage treatment plants as fuel source (refined biogas, hydrogen) in a city.

In contrast to laws that directly affect FCHS, other laws exist that have an indirect affect. An example is the “Bürgerliches Gesetzbuch (BGB)” - the German Civil Code - because it regulates how and under which conditions a house owner can allocate the investment costs for modernising technology to the tenants. Although they have no direct affect, they are partly considered to be barriers for implementing FCHS (UBA05).

In addition to laws concerning FCHS there are also regulations concerning hydrogen. There is, however, no specific law that targets hydrogen, but a number of technical and safety rules that need to be applied. Various industrial hydrogen pipelines in Germany show that the technology exists for transporting hydrogen.

3.2.7 Renewable energy supply

German renewable energy policies aim at reducing climate active emissions/ green house gas emissions, securing the energy supply and reducing dependencies from fuel imports. The overall minimum targets for reducing GHG are set for different energy sectors end years compared to the base year 2000. Table 15 shows the targets.

Table 15: Minimum targets for energy produced from renewable energies

	until 2010	until 2020	until 2050
Total primary energy supply		10 %	50 %
Electric power	12,5 %	20 %	-

In 2007 the target for electricity production has been exceeded with an estimated share of 14 % of electricity produced from renewable energies. In November 2007 the German Federal Government has therefore raised the target for 2020 to 35-40 %.

For electricity generation the most important renewable energy sources are wind energy, hydro power and biomass. With respect to the application of household fuel cell systems in Germany so far only biogas and wind power are of interest and to some extend methanol or ethanol produced from biomass.

3.2.7.1 Biogas

In 2006 approximately 3500 biogas plants were in operation that produced around 5000 GWh of electricity. The newly installed capacity in 2006 was 550 MW. To supply private households that operate small-scale fuel cells with biogas, the biogas needs to be upgraded to natural gas quality and injected into the natural gas grid as described above for the projects in Pliening and Straelen. In Germany currently a total flow rate of 685 m³/ h of biomethane are being fed into the gas grid

Upgrading biogas to biomethane requires additional technology and thus additional investment costs. Therefore biomethane is usually produced at big biogas plants. A minimum flow rate of 500 Nm³/ h of raw biogas, corresponding approximately to a 1 MW_{el} conventional CHP plant, is necessary for an economically viable operation of the upgrading unit.

The resulting costs for the upgraded biogas vary from 0.0487-0.1647 €/kWh depending on the size of the biogas plant and the applied upgrading technology (Figure 8).

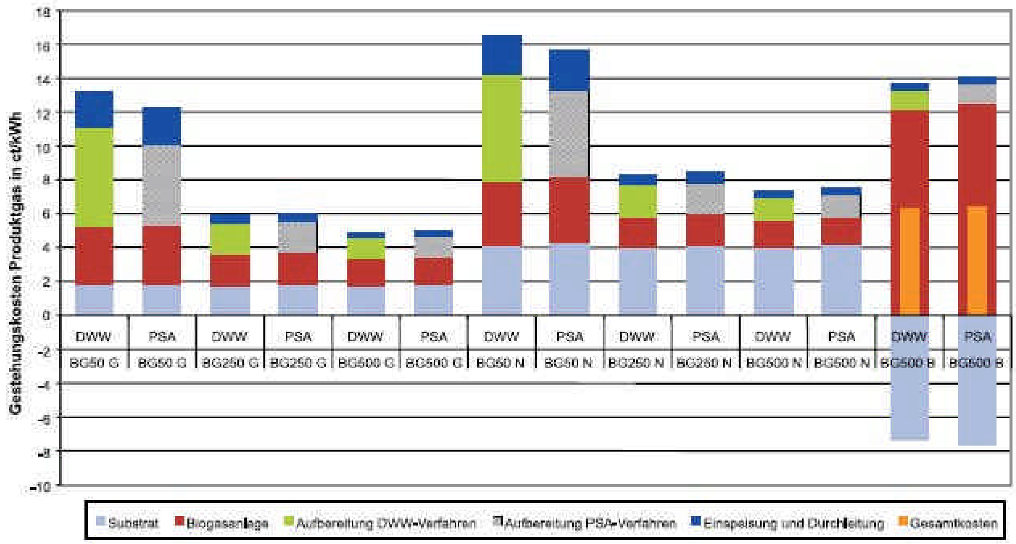


Figure 8: Comparison of specific cost for the upgraded biogas

In general the costs are decreasing with increasing sizes of the biogas plants. The figures also show that the upgraded gas from manure digesting biogas plants (indicated by *G*) – costs less than the gas produced from biogas plants that mainly digest corn or energy crops (indicated by *N*). Differences between the upgrading technologies are less significant. Compared with the current price for natural gas of 0.05-0.07 €/kWh depending on the consumptions of private households only big biogas plants could be competitive.

3.2.7.2 Biomass

Methanol almost exclusively is produced from natural gas. In Germany ZSW has shown that methanol can be produced from biomass by reacting biogas with water and hydrogen. However to our knowledge this production is not done on an industrial scale. It is more promising to

- remove the trace gases and CO2 and then reform the remaining methane for the use in PEMFCs
- remove the trace gases and use high temperature fuel cells after simple prereforming (preferably MCFCs)
- upgrade the biogas to “Syngas”, which then again can be used in high temperature fuel cells or PEMFCs after reforming.

Use in residential fuel cells
As was confirmed by the experience of WS Reformer GmbH, methanol and ethanol can be reformed to PEMFC-quality in the 1 kW range, which is of interest for the residential fuel cell market. This means that the fuel cell has to be adapted to this reformate instead of operation on pure hydrogen.

The producers of ethanol from biomass have their growing market in the transportation sector where ethanol has to be added to gasoline. They are at this moment not interested in the application for reforming and fuel cells for households. Therefore a market for biomass RES-FCHS can only develop in a later stage.

The cost of fuel for the biomass is approximately 0.07 €/kWh (FNR: Biokraftstoffe)

3.2.7.3 Wind energy supply/installations

The amount of installed wind turbines has risen considerably over the last 8 years. In 2005 17.574 windmills were installed in Germany with an output of 18.428 Megawatt. This means a potential of 6.7 % of the German net electricity demand and an annual avoidance of up to 25 Mton CO_2
Most wind energy is obtained in the German states bordering either the North Sea or the Baltic Sea.

Schleswig-Holstein:
In the northernmost German state 30 % of the electricity stems from wind energy. This is made possible by 2.188 wind turbines with an annual output of 1907 MW (see Figure 9).

Mecklenburg-Vorpommern:
In an average year more than 32 % of the states´ electricity demand can be covered through wind energy.

Niedersachsen:
With Schleswig-Holstein and Mecklenburg-Vorpommern, Niedersachsen ranks among the German states with the biggest capacity in wind energy.

These three states with coastlines contribute to about 50% of the installed wind energy.

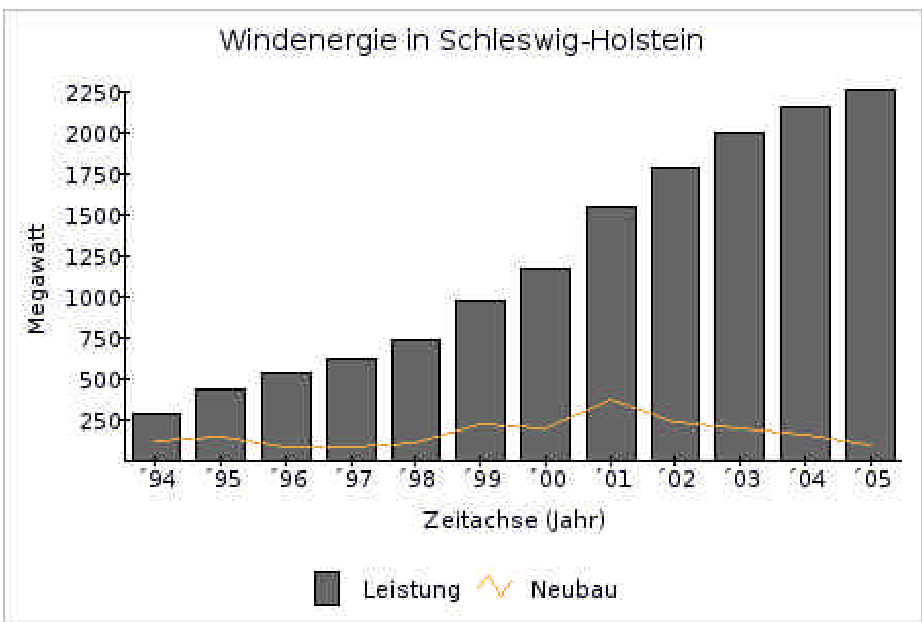


Figure 9: Installed wind power in Schleswig Holstein

The view of Vattenfall [8] about offshore wind parks is:

- Basically the power will be fed into the grid, feed in tariff between 0.08 and 0.09 €/kWh.

- Surplus power can be stored as hydrogen.
- As a rule, this hydrogen will be used to sustain mobility (as hydrogen or after conversion into synthetic fuel).

In the future, smaller quantities of hydrogen may be fed into local hydrogen grids, to supply local city and housing development projects in areas with excess wind energy (e. g. Hafencity Hamburg), where the use of PEM-fuel cells is taken into consideration.

The cost of electricity for the electrolyser directly at the wind turbine is estimated as 0.106 €/kWh.

3.2.8 Present plans for FCHS and key actors

The German national development plan [9] assumes 450 fuel cell units for households by 2010, 2.250 units by 2012, and 72.000 units p.a. by 2020 for Germany. For 2020 the price target is 1.700 €/kW. These figures were aggregated by a survey done with the producers of heating installations, which have closed ranks (http://www.initiative-brennstoffzelle.de/).
EnBW at the moment is testing 16 fuel cell systems. The company is prepared to test more systems, if systems with new promising features are available. Obstacles for the installation of new systems at present are high investment and service costs.

3.2.9 Main barriers

The major barriers for applying household fuel cell systems in Germany are so far the high investment and service costs. For investors – e.g. house owner or energy utilities – the availability of the technology and its reliability are also important aspects. In this respect technological improvements are required, which this project aims for.

For the utilisation of biogenic gases the direct use in a MCFC is a competing technology, which is currently being tested in several sites in Germany. Technical improvements and decreasing prices are also required for this technology to compete with conventional CHP-units.

With respect to PEM fuel cells the competing application is the transport sector, but also in this sector technical improvements and price reductions are needed.

Barriers also exist in the German legislation. Although Germany supports fuel cells through all laws related to heat and power generation – e.g. via increased feed-in tariffs – the legislation concerning house owners and landlords is not supportive. Investments costs in new technologies – e.g. in new heating systems – can only to some extend be allocated to the tenants. Especially for expensive technologies this is a disadvantage.

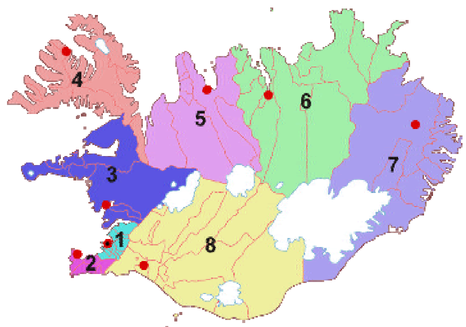
3.2.10 Contacts

- Mr. Gruber and Dr. Weinmann, Vattenfall, energy company
- Mr. Hofmann from Mahler AGS, reformer company
- Baxi Innotech Hamburg, fuel cell system company
- Mr. Edel, EnBW/Stuttgart, one of the big four power suppliers of Germany, responsible marketing manager for fuel cell field tests
- Dr. Pehnt, IFEU - institute/Heidelberg, possible implementation of RES-FCHS in a new housing area in Heidelberg
- Prof. Heinzel, ZBT institute/Duisburg, reforming
- Dr. Schmid, WS Reformer/Renningen, reforming
- Mr. Bergmair, Profactor/Steyr-Austria, process to upgrade biogas to natural gas quality

- Dr. Hinz, Suedzucker Bioethanol GmbH/Mainz, production of bio-ethanol
- Mrs. Renault, Winpro Engineering Company, questionnaire use of "surplus wind energy"
- Dr. Specht, ZSW institute/Stuttgart, technical discussions concerning efficiency and project matters
- Dr. Krewitt, DLR institute/Stuttgart, technical discussions concerning efficiency and project matters
- Mr. Wolfgang Lotz, Stadtwerke Esslingen GmbH & Co.KG, regional market
- Mr. Yves Membrez, EREP SA, Switzerland, operation of fuel cells with biogas
- Prof. Weiland, FAL Braunschweig, he conducted laboratory tests with PEM-fuel cells and biogas, we spoke about his results and experiences
- Stadt Bottrop, they are producing hydrogen from sewage gas, I investigated about the possibility to introduce FCHS, they said it's too early for such a project
- Gregor Heckenkamp, Ingenieurbüro für Biogastechnik, expert for gas upgrading technology
- Herr Gerdes, Haase Energietechnik, gas upgrading technology, costs for biogas upgrading
- Dr. A. Schulte, Carbotech Anlagenbau GmbH, gas upgrading technology, costs for biogas upgrading
- Dr. Günther, DGE Wittenberg, gas upgrading technology, costs for biogas upgrading
- Herr Tentscher, ECO Naturgas Handels GmbH, costs for biogas upgrading and technologies applied in Germany
- Herr Rohrig, ISET e.V., he explained what happens with excess wind power in Germany
- Mr. Bödecker, BBI BÖDECKER IMAGINEERING GMBH, situation of methanol production from biomass
- Mr. Sörensen, Agro Service Nord GmbH, interview about Methanol in Germany

3.3 Two representative regions in Iceland.

3.3.1 Description of two regions in Iceland: Reykjavik and Western Fjords.



The Reykjavik area is situated in the southwest part of Iceland and is denoted number 1 on the map. As a highly modernised capital of one of the most developed countries in the world, its inhabitants enjoy a first-class welfare system and city infrastructure. The financial sector and information technology are now significant employers in the city. The next tables are for the Iceland as a whole. Whenever specific information for Reykjavik area is available this will be provided.

In the Western Fjords, the area marked (4) on the map, only about 400 inhabitants enjoy geothermal heating and about 500 inhabitants enjoy waste-incinerator based central heating. About 80% of the inhabitants have to resort to electrical grid-based heating of houses.
In the Western Fjords of Iceland there is a great demand for solving the problem of central heating with alternative methods.

Table 16: Characteristics on houses and inhabitants for Iceland and Reykjavik area

Characteristics	Iceland	Reykjavik area
Inhabitants (*1000) (2007)	313	200
Inhabitants/km^2	3.1	187

3.3.2 Infrastructure

The Table 17 describes the connections of the household to the public grids. Heating is supplied by geothermal energy. In the Reykjavik area (1) all houses are connected to the central heating system.
In the Western Fjords, most heating is done by grid connection. Figure 10 show the development in time of the heat sources for space heating. Geothermal heat provides 87% of the required heating.

Table 17: Energy distribution infrastructure to houses in Iceland

Energy infrastructure to houses	Iceland
Electricity grid	99.99%
District heating grid	2900 km

3.3.3 Household energy system demand

Table 18 presents figures for the energy consumption in Icelandic households.

Table 18: Energy consumption of households in Iceland

Consumption patterns for households	Iceland Average household	Unit
Electricity consumption	4300	kWh/yr
Energy consumption for space heating	27000	kWh/yr
Energy consumption for tap water	Part of heating	kWh/yr

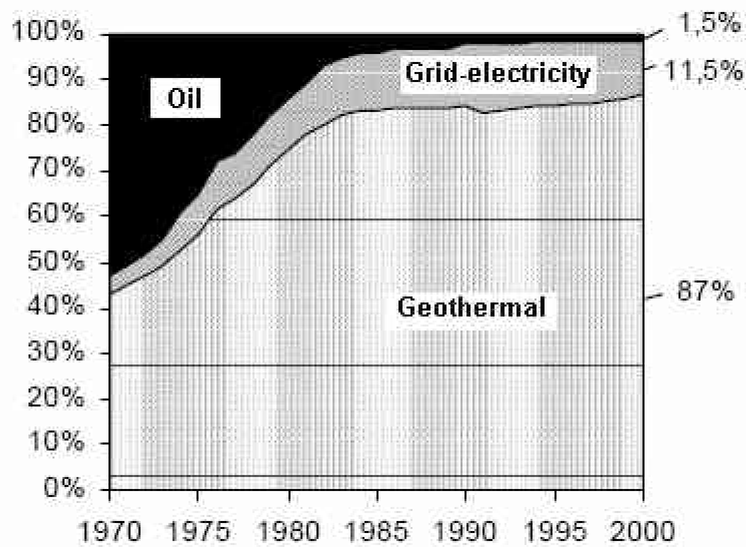


Figure 10: Development of sources of house-heating in Iceland 1970 - 2000

3.3.4 Household cost for heat and electricity

Table 4 gives an overview of the average energy prices for Icelandic household in 2007.

Table 19: Energy prices including taxes for households in Iceland

Energy prices for households	Iceland	Unit
Electricity price	0.09	€/kWh
Energy price for space heating	0.02	€/kWh
Energy price for tap water	0.02	€/kWh

The price of electricity varies a lot in Iceland depending on use and quantities. The most favourable prices are found in the heavy industry sector where prices in the range of 0.015-0.02 €/kWh are common for electricity to aluminium plants. The price is regulated with aluminium price on the London Metals Exchange. Electricity for use for house heating in the less geothermal areas of Iceland such as in the Western Fjords would be much lower than in the urban geothermal areas of Reykjavik where geothermal heat is enjoyed.

When quoting a price for electricity in Iceland we will be using the 0.09 €/kWh.
The range can be all down to half of this price for special cases.

3.3.5 Feed-in tariff and subsidies

Due to the well established geothermal infrastructure and hydropower no specific subsidies or feed-in for renewable energy exists.

3.3.6 Regulations for small-scale CHP and hydrogen

In 2006 Iceland was using about 72 % of its energy from renewable resources, mainly hydroelectric and geothermal. This ratio is the highest of any country. The remaining 28% are mainly imported fossil fuels, oil, gasoline, fossil gas and coal. The use of fossil fuels is mainly in three sectors: in powering the transport sector, in powering the fishing fleet and finally in industry where imported coal and electrodes for ferrosilicon and aluminium smelting are an important sector.

The production of electricity for use in aluminium smelting and ferrosilicon production now amounts to about 1 GW of power. 80% of this power comes from hydroelectricity. The rest stems from geothermal energy. On the other hand, the geothermal harnessing has resulted in almost all houses and dwellings in Iceland being heated with geothermal heat. The geothermal steam turbines working at around 260 °C usually produce enough combined power and heat to be utilised in the municipal heating systems of most of Iceland.
To take an example, the use of geothermal heat in Reykjavik and surrounding cities has displaced about 750 thousands of tons of coal which would have been needed in the original fossil based heating of this Nordic city.

There exists a tax exempt for H_2 vehicles.

3.3.7 Methanol supply/installations

The most likely scenario is that methanol will be produced in the Reykjavik area from exhaust from metal smelters like the ferrosilicon smelter at Grundartangi. Hydrogen needed for the hydrogenation of the CO_2/CO is likely to come from an electrolysis plant also operated from renewable electricity. The expected transport mode is by large trucks. In the Western Fjords there would be depots of methanol close to the service centres in the closest communities.
In the old oil based heating system in the Western Fjords, oil was transported over long distances and kept in up to one tonne container-tanks close to each house.

3.3.8 Present plans for FCHS and key actors

The likelihood for a hydrogen residential fuel cell system by reforming methanol in Iceland is generally low. This comes about because of the combined electricity network and geothermal heating.

However, a considerable number of dwellings out in the countryside are outside the reach of the geothermal distribution systems. These are the increasing market of summer residences many of which are built for permanent use and of considerable quality. In cases where these dwellings are not grid connected they have been a market for oil heating, for propane gas heating and experiments with small wind turbines or the like. The number of such dwellings is in the range of 10.000 to 12.000.
An anticipated number of 100 leisure houses could be foreseen to operate a methanol based household fuel cell system.

The use of DMFC's in the case of recreational dwellings in Iceland will be addressed specifically in the RES-FC Market project. Here, most of the expected use is linked to either hydrogen being transported and used or methanol, which could lead too much easier transport and storage facilities. For reasons previously explained the use of hydrogen based residential fuel cells will not be undertaken as a part this project. On the other hand, the important learning curve from the ECTOS and related projects will be a valuable contribution to the general philosophy of increasing the use of hydrogen and fuel cells in general.

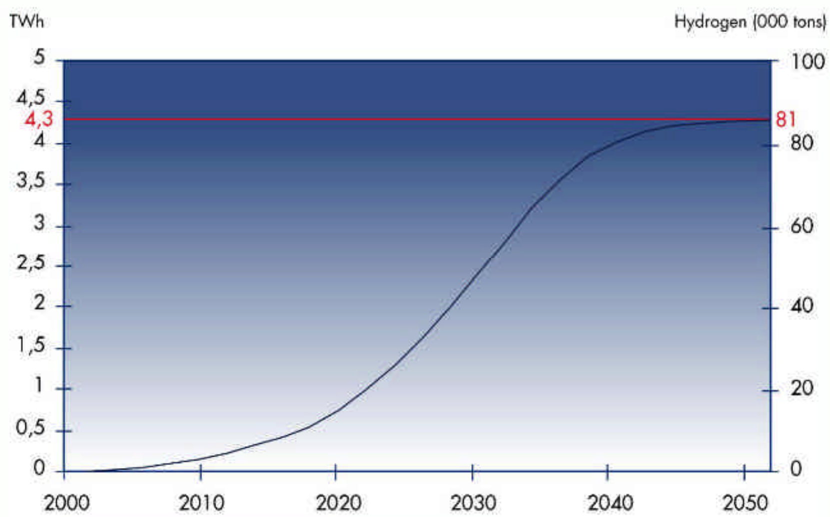


Figure 11: The anticipated use of hydrogen in Iceland 2000-2050.

In Figure 11 the anticipated use of hydrogen in Iceland 2000-2050 is presented. The total of 81.000 tons of H_2 is needed in a full fledged H-economy where transport and fishing are using hydrogen while residential power and heat are mostly served by grid and geothermal centrally based heating.

The key actors in Iceland are:

- Carbon Recycling International
- Landsbankinn bank
- Sudurnes Municipal heating company
- OLIS the former agent for British Petroleum in Iceland

3.3.9 Main barriers

Presently the power system in Iceland is based on a combination of electricity from hydroelectric or geothermal plants and geothermal space heating. Often these are a result of a combined power and heat geothermal cycle. A good example is Reykjavik where geothermal energy is harnessed in Nesjavellir east of the capital. The electricity is harnessed by the use of flash turbines operating on 260 °C steam. The effluent of the turbines is transported to Reykjavik through a geothermal pipe of about 30 km as water close to boiling point. The water is subsequently distributed through Reykjavik as a part of the municipal geothermal heating system.

When methanol based CHP is considered it seems obvious that the system will look more complicated and possibly cumbersome. So we would expect some barriers from the general public to accept the new methanol system.

On the other hand there have been successful demonstration experiments with hydrogen for transport – starting with three buses in Reykjavik in 2003 and now extended to about a dozen hydrogen powered cars receiving hydrogen from a hydrogen fuelling station on the outskirts of the capital city.

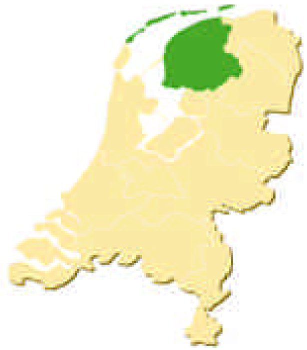
Generally the public in Iceland has been positive towards the introduction of a new fuel base for transport. If the methanol production will be seen as a part of a hydrogen economy it remains to be seen if public acceptance follows easily.

3.3.10 Contacts

- Dr. Gudmundur Gunnarsson and Mrs. Dora Hlin Gisladottir, Innovation Center Iceland;
- Dr. K.C. Tran, CEO of Carbon Recycling International, Iceland;

3.4 North Friesland, the Netherlands

3.4.1 Description of North Friesland



Friesland is situated in the north of the Netherlands, see the map, and is mainly an agricultural province. Also tourism, mainly on the lakes in the south west of the province, and on the islands in the Wadden Sea in the north, is an important sector. In Table 20 the characteristics on houses and inhabitants for the Netherlands and Friesland are provided. Specific information on the number of new houses in districts with more than 200 houses is not available.

The other tables are for the Netherlands as a whole. Whenever specific information for Friesland is available this will be provided.

Table 20: Characteristics on houses and inhabitants for the Netherlands and Friesland.

Characteristics	The Netherlands	Friesland
Inhabitants (*1000)	16.334	643
Houses (*1000)	6967	275
Inhabitants/km^2	394	192
New/existing houses (%/yr)	1.03%	0.99%

3.4.2 Energy infrastructure for heat and electricity

In the Netherlands natural gas is the dominant source for space heating as well as for tap water heating. About 97% of the houses and apartment buildings are connected to the natural gas grid (Table 21). In 2006 84% of the houses were equipped with a central heating boiler. In almost 65% of the cases this was a so-called high efficiency boiler (HE-107). The market share of this type of boiler steadily increases, replacing less efficient types, as clearly illustrated by Figure 12. The amount of houses without a central heating boiler still decreases. These houses are connected to a district heating grid or a local heating grid (apartment buildings), or use a stove for space heating. In most of these cases a separate electric or gas-based heater is used for tap water heating.

According to the Central Bureau of Statistics a cumulative amount of almost 31,000 heat pumps were installed in the Netherlands in 2005. Most heat pumps are installed in the industry and commercial buildings, like offices. However, heat pumps are found increasingly in houses, especially new housing estates. In 2005 more than 1600 new houses were equipped with a heat pump on a total of about 67,000 new houses.

With regard to electricity Table 21 shows that almost all houses in the Netherlands are connected to the electricity grid. In 2005, about 101 TWh of electricity is produced in the Netherlands. More than 90 TWh originated from coal and natural gas. Almost 4 TWh was produced from nuclear. Renewables accounted for 7 TWh, of which 5 TWh were from biomass and the remaining 2 TWh from wind (mainly), water and solar-PV. About 19 TWh was imported of which more than 50% (9.8 TWh) was produced from renewable sources. In 2005, the installed production capacity consisted of about 9,9 GW of conventional power plants, 10.6 GW of combined heat and power plants and 1.3 GW of wind, water and solar power. The latter figure has increased to almost 1.6 GW in 2006, the main part of this capacity being wind (>1.4 GW).

According to an inventory done in the EU project Roads2HyCom more than 230 km of hydrogen transport and distribution pipelines are present in the Netherland. These pipelines are all industrial pipelines and are located in the southwest part of the Netherlands, especially in the Rotterdam harbour area and the area in between Rotterdam and Antwerp in Belgium. The pipelines are owned by Air Liquide (about 80%) and Air Products (about 20%). Up to now no houses in the Netherlands are connected to a hydrogen grid.

Table 21: Energy distribution infrastructure to houses in the Netherlands.

Energy infrastructure for houses	Share of houses connected to the grid
Electricity grid	>99.99%
Natural gas grid	97%
Small scale heating grid (flats etc)	6%
District heating grid	4%

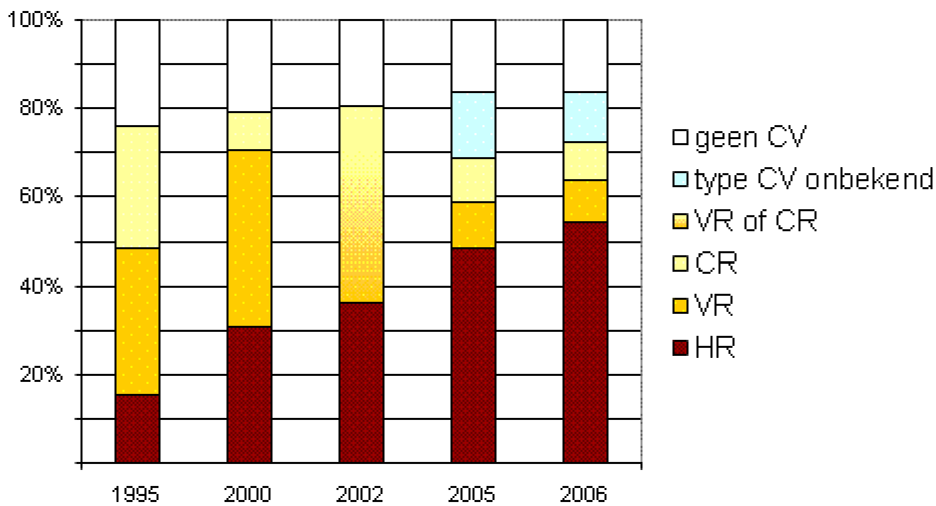


Figure 12: Trend in the application of boilers for heating applications (HR = High efficient boiler ; VR = improved efficiency boiler).

3.4.3 Household energy system demand

Table 22 presents figures for the energy consumption in Dutch households. In 2006 the natural gas consumption of an average household of 2.3 persons amounted to 1652 m^3. The average household gas consumption decreased between 1990-2006 with about 23%. This is mainly due to a decrease in demand for space heating as a result of better insulation of houses and an increase in application of high efficiency boilers.

New houses have to meet energy standards. Houses currently built have to satisfy an energy performance coefficient (EPC) of 0.8. The average EPC of Dutch houses that relates to the average household figure in Table 3 is above this value. Current policy measures of the Dutch government are aimed at improving the energy standards for houses. The policy plan is to lower EPC to 0.6 in 2011 and to lower the EPC further to 0.4 in 2015. Table 3 presents indicative values for a house with an EPC value of 0.6.

Table 22: Energy consumption of households in the Netherlands

Consumption patterns for households	The Netherlands Average household 2006	The Netherlands New house (EPC=0.6)	Unit
Electricity consumption	3400	3400	kWh/yr

Energy consumption for space heating	10600	5800	kWh/yr
Energy consumption for tap water	3400	3000	kWh/yr
Energy consumption for cooking	600	600	kWh/yr

In 2006 the electricity consumption of an average Dutch household amounted to 3400 kWh. The electricity demand per household increased with about 20% in the period from 1990 to 2006. For the time being this trend is likely to continue. Extrapolation of this trend would result in an electricity consumption per household of 3800 kWh in 2015 and would cross the amount of 4000 kWh in 2020.

A typical electrical load profile for a household is shown in Figure 13. The load profile shows peak demands well above 1 kW. However, such high demands only occur during a small part of the time. The profile shows that a 1 kW FC system that can be operated between 200 W and 1 kW could directly meet about 80% of the electricity demand. In this typical example 12% of the demand is above 1 kW and 8 % lower than 200 W.

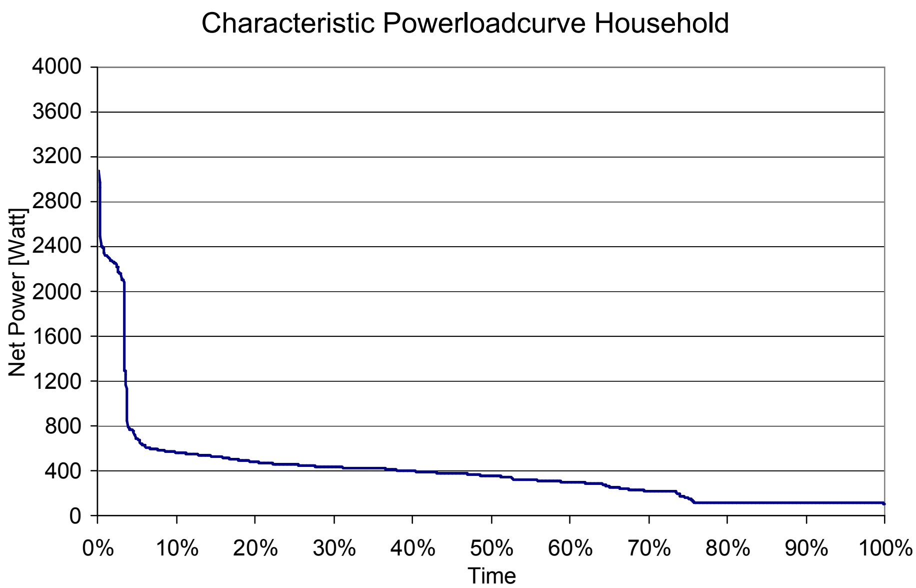


Figure 13: Typical daily power load curve for a Dutch household.

3.4.4 Household cost for heat and electricity

Table 23 gives an overview of the average energy prices for a Dutch household in 2007. Heat for space heating and tap water is largely produced from burning of natural gas in boilers. The consumer price of natural gas in 2007 consisted of about 3.7 €ct/kWh (10.3 €/GJ) for the natural gas and 2.8 €ct/kWh (7.8 €/GJ) of taxes (energy tax and VAT). The contribution of transport of the gas is only small; somewhat more than 0.1 €ct/kWh (0.4 €/GJ). For the heating grid the policy is that consumers will not pay more than in the case that they would be connected to the natural gas grid. So the price of heat is the same as for natural gas.

The consumer price of electricity amounted to 21.8 €ct/kWh in 2007, of which about 7 - 8 €ct is for the electricity itself. Transportation contributes 3 - 4 €ct to the electricity price, the rest being taxes, both energy tax and VAT.

Over the past years about 35 - 40% of the Dutch households had a subscription for "green electricity". The consumer price of "green electricity" is approximately equal to the price for the Dutch electricity mix. Some energy companies also offer the possibility to purchase "Green gas". However, up to now this is not gas produced from biomass, but natural gas for which the corresponding CO_2 emission is compensated by planting trees. The price of "green gas' is usually somewhat higher than of regular natural gas. It is not known how many households have a "green gas" subscription.

Table 23: Energy prices including taxes for households in the Netherlands

Energy prices for households	The Netherlands	Unit
Electricity price (Eurostat 2007)	0.218	€/kWh
Natural gas price (Eurostat 2007)	0.066 *)	€/kWh
Energy price for space heating	0.066	€/kWh
Energy price for tap water	0.066	€/kWh

*) based on use of Groningen natural gas with a heat content of 8.8 kWh/Nm^3

3.4.5 Feed-in tariff and subsidies

With respect to feed-in tariffs a distinction should be made between small and large generators. At this moment, there are no special feed-in tariffs in the Netherlands for electricity produced by small-scale CHP units in households. Up to now the feed-in arrangement designed for photovoltaics applies. This leads to the following feed-in tariffs:

- 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;
- 0.079 €/kWh if the amount of feed-in does not exceed the amount of electricity withdrawn from the grid but lies within the range 3000 - 5000 kWh
- In all other cases the feed-in tariff equals the feed-in tariff for the business or commercial market which for PV is 0.7 * the mean price of electricity at the Amsterdam Power eXchange (APX), and results in a tariff of approximately 0.03 - 0.04 €/kWh.

The feed-in tariff for electricity from large commercial generators is based on the average APX spot market price and a factor for the predictability of the supply. This factor is lower for wind energy than for e.g. biogas installations. Figure 14 shows the average spot market price for electricity during the day for the period January-June in 2005. The graph shows that within one day the electricity price variation is a factor 2.5. The average price during the day lies around 40 - 50 €/MWh.

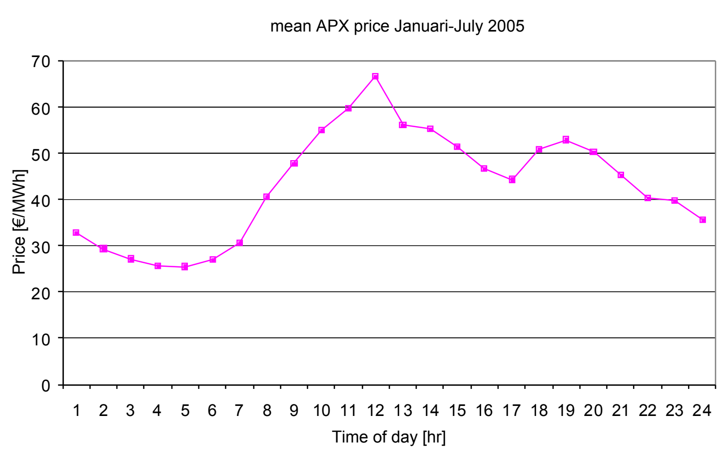


Figure 14: Average electricity spot market price in the Netherlands per hour of the day

The feed-in tariffs for large commercial generators are well below the production cost of most renewable energy options. To stimulate electricity production from renewables subsidies are available to bridge the gap. In the latest subsidy program, subsidies were allocated to renewable energy projects for a period of maximum 10 years. The program (MEP) stopped allocating subsidies to new projects in the Netherlands in August 2006 because enough projects were in place to meet the target of 9% renewable electricity in 2010. On top of the feed-in tariff and MEP subsidy, options generating electricity from biomass may benefit from a EU subsidy for cultivation of energy plants on set-aside lands. An overview of the tariffs is shown in Table 24.

Table 24: Overview of feed-in tariff and subsidies for renewable energy from the MEP program.

Renewable energy option	Tariff/subsidy	Unit
Electricity feed-in tariffs	0.03-0.04	€/kWh
Subsidy electricity from wind energy	0.065	€/kWh
Subsidy electricity from biomass	0.097	€/kWh
Subsidy electricity from biogas	0.097	€/kWh
EU subsidy for cultivation of energy plants on set-aside lands	45	€/ha

A new subsidy program (SDE) for large-scale commercial production of renewable energy was announced in October 2007 and will probably start April 2008 for reaching the targets of 2020. The subsidies from this programme are shown in Table 25. In contrast to the previous MEP program, in the SDE program the subsidy changes if the feed-in tariff (set at 0.04 €/kWh) changes, the total of the feed-in tariff and the subsidy will stay constant.

Table 25: Subsidies for renewable energy options from the announced SDE program.

Renewable energy options	Subsidy	Unit
Subsidy wind energy		
onshore	0.028	€/kWh
offshore; 20 km	In 2009	€/kWh
offshore; 40 km	In 2009	€/kWh
Subsidy biomass (<10 MW_e)	0.053	€/kWh
Subsidy biogas (<10 MW_e)	0.053	€/kWh
Biogas production	0.070	€/m^3

For renewable energy projects specific subsidies and/or fiscal arrangements (EIA) are available. For demonstration projects a subsidy of 40% can be obtained (EOS-DEMO or UKR program) on the extra cost of hardware compared to the cost of a reference system. For energy projects near to the Wadden Sea, as in Friesland, an additional project subsidy from the Waddenfonds is possible.

3.4.6 Regulations for small-scale CHP and hydrogen

In January 2007 the three largest Dutch energy companies Essent, NUON and ENECO, together with the Dutch gas company GasTerra started a large project for the installation of 10.000 micro-CHP units operating on natural gas in the period 2007-2009. The units will mainly be Stirling engine based units, but also fuel cell systems will be taken into account, if available. However, the latter will have to run on natural gas, so has to include a small reformer. In preparing the business cases it was found that for electricity from a micro-CHP unit that is fed into the grid, energy taxes have to be paid twice. The first time is for the natural gas used to produce the electricity, and the second time when the "kWh" is withdrawn from the grid again by a consumer. Although all stakeholders involved, including responsible authorities, agree that this is a problem that should be solved, no final solution for the issue is yet in place. For these systems was found that the energy tax that has to be paid for the natural gas was not refunded when feeding electricity back into the grid.

In addition to financial arrangements to support innovative and renewable energy options, all kinds of regulations have to be in place for the technical integration and safe use and operation of new energy conversion systems (fuel cell based micro-cogeneration system, FCHS) and new energy carriers (hydrogen). Because of the developments in the field of small-scale CHP for houses and previous experiences with PV, adequate regulations exist for this application. These regulations for example deal with grid connection, power quality and island operation in case of grid failure. No regulations exist yet for the application of H_2 in households. A specific issue in this field is the use odorants. Odorants are added to natural gas to be able to detect leaks. Standard odorants for natural gas, however, are not suitable for hydrogen. The difference in specific density of the odorants and hydrogen is too large causing separation of the gases, and hydrogen diffuses much more easily through small leaks than the odorants so there can be a leakage without anyone noticing it because there is no leakage of odorant.

3.4.7 Wind energy supply and installations

The main issues driving Dutch energy policies are climate change, security of supply and local air quality. Targets for the near future are to reduce GHG emission by 6% compared to the 1990 level in 2012 as part of the Kyoto-protocol agreements and to increase renewable electricity production to 9.0% of the total amount of electricity produced in the Netherland by 2010. Last year the government presented a new policy program with targets for 2020. These targets are:

- Reduction of CO_2-emissions with 30% compared to the level of 1990
- Increase of energy saving to a level of 2%/yr
- Increase in the use of renewable energy up to a level of 20% of the total energy used in 2020.

As a result of these ambitions it is expected that the amount of wind power installed on land will double within a few years from now, from currently about 1500 MW (2007) to 3000 MW. The plans for 2020 foresee even larger numbers with up to 4000 MW of wind power onshore and 6000 MW offshore. If these number materialise "excess electricity" from wind may become reality. A study by TenneT (the Dutch grid operator) shows that for 2000 MW onshore and 6000 MW offshore about 5 TWh of “excess electricity” is available for international trade or other options during hours of high wind power production and low electricity demand. “Excess electricity” exists in this case for approximately 18% of the time.

At the end of 2006, the installed wind energy in Friesland is 127 MW, see Figure 15. For the Netherlands as a whole, the installed wind power is 1457 MW. By dividing the number of households for the Netherlands and Friesland from Table 1 by the amount of installed wind power, the installed capacity per household in Friesland appears more than twice the Dutch average. In the Netherlands there are almost 4800 households per MW installed while in Friesland there are about 2150 households per MW installed. In addition, Friesland is a province with relatively few industrial activities. So with the increase in wind power as foreseen Friesland may very well be the first area in the Netherlands to experience a local "excess of electricity".

If "excess electricity" is available during hours of high wind power production and low electricity demand, it can be used for production of hydrogen. The price of this electricity is assumed to equal the price of off-peak electricity. For 2005 the price of off-peak power for use in an electrolyser of about 1MW capacity is estimated as 0.059 €/kWh. This estimate is based on the average electricity spot market price of 0.029 €/kWh between 23.00 hrs and 07.00 hrs (see Figure 10), 0.02 €/kWh transportation costs and 0.01 €/kWh taxes.

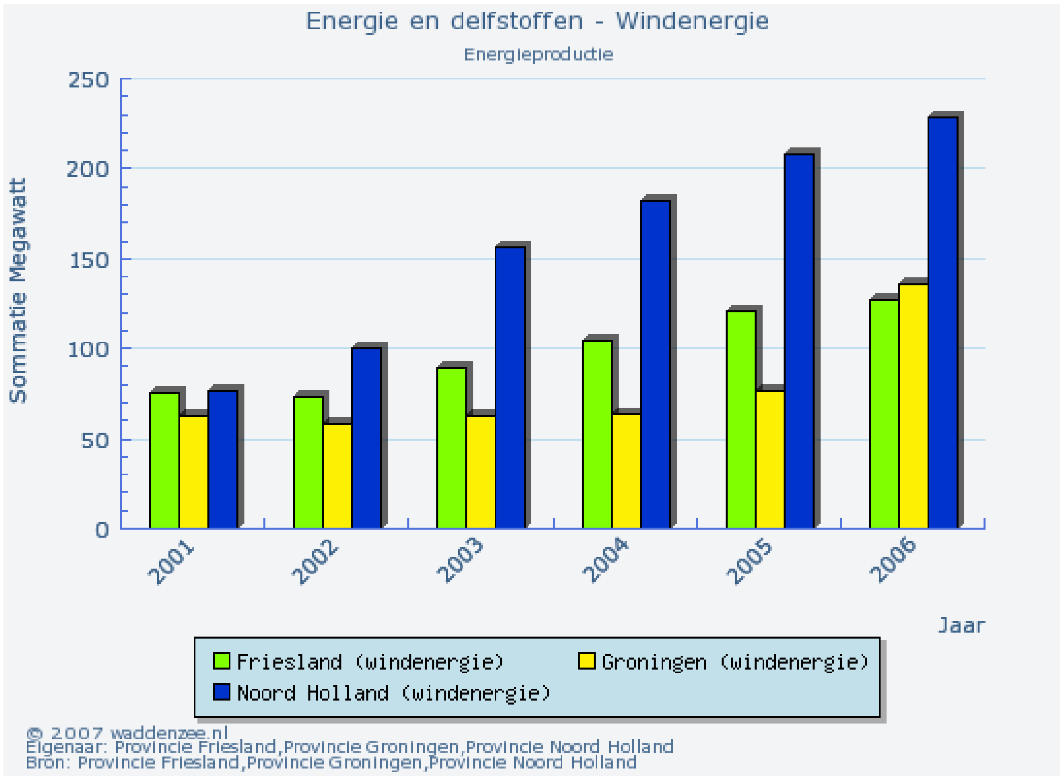


Figure 15: Total installed wind power plants in 3 provinces in the north of the Netherlands

3.4.8 Present plans for FCHS and key actors

There is a large project for the installation of 10.000 micro-CHP units in the period 2007-2009. The units will mainly be Stirling engine based units, but also fuel cell systems will be taken into account, if available. All these systems, however, will be fuelled by natural gas. Natural gas has to be replaced by biogas or Bio-SNG (SNG stands for Synthetic Natural Gas) to obtain a more sustainable option. Nuon announced in February 2008 that they will purchase 10.000 2 kW SOFC residential fuel cell household systems per year, delivery starting by the end of 2009. These units will operate on natural gas.

There are no specific national or regional plans, nor targets, for the development and implementation of renewable hydrogen fuelled fuel cell cogeneration systems for households. Two "communities" have been contacted, i.e the city of Leeuwarden in the province of Friesland and the city of Arnhem in the province of Gelderland, that are interested in housing fuel cells for households in the near future. Officers in both cities expect that a demonstration project for fuel cells in households will probably be limited to a maximum of about 20 households mainly for financial reasons (subsidies and risk).

In Arnhem there is a so-called "citizen initiative" (De Stoere Houtman) for renewable energy with hydrogen as buffer/energy carrier. The plans include 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 H_2 & FC Platform (HFP). They take this as a sign that ‘Brussels’ is interested in the idea and would be interested to support De Stoere Houtman’s project which is probably the first “citizens’ initiative” worldwide for applying hydrogen and fuel cells in houses. The first desk studies, however, indicated that for safety reasons a hydrogen grid into the houses is at this moment a step too far. For example, no suitable odorants for hydrogen exist yet to be able to detect small leaks like in the case of natural gas.

Key actors for a development or project on RES-FCHS in the Netherlands would be:

- Communities interested in fuel cells for households: Leeuwarden and Arnhem.
- People from the "De Stoere Houtman" project.
- SenterNovem is an agency of the Ministery of Economic Affairs responsible for managing many of the R&D and subsidy programs in the Netherlands in the field of innovation, energy and environment.
- Especially for the northern part of the country, including Friesland, Energy Valley would be a valuable partner. Supported by public authorities and business, Energy Valley is an organisation for initiation, development and coordination of renewable energy projects in the north of the Netherlands.
- The consortium for the introduction of micro-CHP in Dutch houses.
- Dutch wind industry and industry in the field of hydrogen and fuel cells like HyGear (small-scale reformers) and NedStack (PEM FC systems)
- ECN is the national research institute in the field of energy including a department for policy studies, and technology development departments on wind energy and on hydrogen and fuel cells (both components and systems).

3.4.9 Main barriers

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.

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

- The cost of fuel cell household systems is still too high for commercial application. This is one of the reasons for the project.
- The lifetime for fuel cell systems needs to be extended.
- 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.
- The public has no experience with hydrogen as an energy carrier.

For Friesland and for the Netherlands barriers exist on:

- There is no excess wind energy available in the Netherlands or Friesland at this moment for providing renewable hydrogen.
- 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 itself are not mentioned.
- 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.

Other developments that can hamper the market development of “renewable hydrogen” based fuel cell household systems:

- Competing options to introduce renewable energy in households.

- 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 the EU (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.

Hydrogen as an electricity storage medium

Hydrogen has the potential to be a storage medium for electricity, as electricity can be used to produce hydrogen through electrolysis, while that same hydrogen could then produce electricity using the same device, i.e. *PEM fuel cells/electrolysers. Using hydrogen to store electricity is an option that might be attractive for intermittent renewable electricity sources. Tiax (2002) has compared various short-term electricity storage options, including the use of fuel cells and hydrogen. Although lead-acid batteries were the least-cost option, with a capital cost of only USD 210/kW, Tiax estimates in the long-run that the cost of a PEM system could be similar (USD 220/kW). However, the overall energy efficiency would only be 45% for the fuel cell and hydrogen storage, compared to 85% for the lead-acid battery. The production of hydrogen from electricity at times of low demand, followed by use in fuel cells during peak demand periods is not a viable competitor to battery storage. Regarding large-scale electricity storage, pumped hydro and underground pressurised air storage show better characteristics (higher efficiency and lower cost) than the fuel cell and hydrogen option. Hydrogen could also be produced from off-peak electricity and stored for later use,* e.g. *as a transportation fuel, resulting in better use of existing electrical capacity. Depending on the choice of diurnal or seasonal production patterns, the hydrogen storage capacity required might vary significantly. The problem with the production of hydrogen from off-peak electricity is that the electrolyser capacity factor would be low (in the order of 20-30%). This would significantly increase the cost of the hydrogen produced, even if electrolysers decline in price substantially. For example, at USD 0.03/kWh, the electricity cost would amount to USD 11/GJ H2 and the total production cost would be around USD 15-17/GJ H2.*

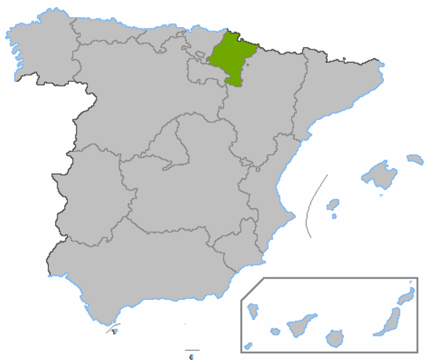
From IEA (“prospects for Hydrogen and fuel cells”; p.71; 2005)

3.4.10 Contacts

- B. de Boer representing the community Leeuwarden and Province Friesland.
- M. Kroon representing the community Arnhem.
- F. Denys representing SenterNovem, energy agency.
- J-P. van der Meer representing Nedstack, fuel cell company

3.5 Navarra, Spain

3.5.1 Description of Navarra



Navarra is situated in the north of Spain, as shown on the map. As in other autonomous regions in Spain, health, employment, education and social services, together with housing, urban development, environment protection policies are under the responsibility of its own institutions. The next tables are for the Spain as a whole. Whenever specific information for Navarra is available this will be provided. Navarra is a strong industrialised region.

Table 26: Characteristics on houses and inhabitants for Spain and Navarra.

Characteristics	**Spain**	**Navarra**
Inhabitants (*1000)	45200	606
Houses (*1000)	23859	293
Inhabitants/km^2	84	58
New/existing houses (%/yr)	2.56%	2.38%

3.5.2 Energy infrastructure for heat and electricity

With regard to electricity, Table 27 shows that almost all houses in Spain are connected to the electricity grid. In 2006, about 276 TWh of electricity was produced in Spain, 69 TW originated from coal, 67 TW from natural gas and 60 TWh was produced from nuclear. Renewables accounted for 29 TWh, of which 23 TWh were from wind. The installed production capacity in 2006 consisted of about 45.2 GW of conventional power plants, 16.4 GW of combined heat and power plants and 11.6 GW of wind power.

In 2006, 70% of the population in Spain lived in towns with a natural gas distribution system, but approximately only 41% of the population in Spain had natural gas in their home. Spain has excellent potential for natural gas market growth, last year the rate of growth was 4.1%.

It is necessary to take into account that only 48% of the houses in Spain have heating, due to the hot weather in the south of Spain. In spite of that, natural gas is the most important fuel to produce heat for space heating into the households. In Navarra 90% of the houses have heating.

Table 27: Energy distribution infrastructure to houses in the Spain

Energy infrastructure to houses	**Spain**
Electricity grid	99.99%
Natural gas grid	94%
District heating grid	n.a.

3.5.3 Household energy system demand

The average energy consumption of a household in Navarra is around 11000 kWh/year, but energy demands change a lot between different types of household, for example in a semidetached house the energy consumption is about 21.500 kWh/year.

Both space heating and hot water represent approx. 70 % of end-energy-use of Spanish households. According to IDAE the residential energy consumption could be distributed in the following way:

heating (40,4 % of the total consumption), followed by domestic hot water (26,9 %), electrical appliances (12,0 %), cooking (11,6 %) and lighting (8,7 %). Nowadays the air conditioning is becoming more relevant (0,4 %).
Table 28 presents figures for the energy consumption in Spanish households. Energy consumption for cooking is including into electricity consumption.

Table 28: Energy consumption of households in Spain

Consumption patterns for households	Spain Average household	Unit
Electricity consumption	3300	kWh/yr
Energy consumption for space heating	5500	kWh/yr
Energy consumption for tap water	2200	kWh/yr
Energy consumption for cooking	In total	kWh/yr

3.5.4 Household cost for heat and electricity

Table 29 gives an overview of the average energy prices for Spanish household in 2007. In this project we have assumed that heat for space heating and domestic hot water is produced by natural gas. The consumer price of natural gas is 0.051 €/kWh including taxes. The consumer price of electricity is 0.116 including taxes.

Table 29: Energy prices including taxes for households in Spain

Energy prices for households	Spain	Unit
Electricity price (Eurostat 2007)	0.116	€/kWh
Natural gas price (Eurostat 2007)	0.051	€/kWh
Energy price for space heating	0.051	€/kWh
Energy price for tap water	0.051	€/kWh

A typical household load profile is shown in Figure 16. This profile shows that a 1 kW FC system due to occasionally larger demand than 1 kW can directly meet up to 90% of the electricity demand.

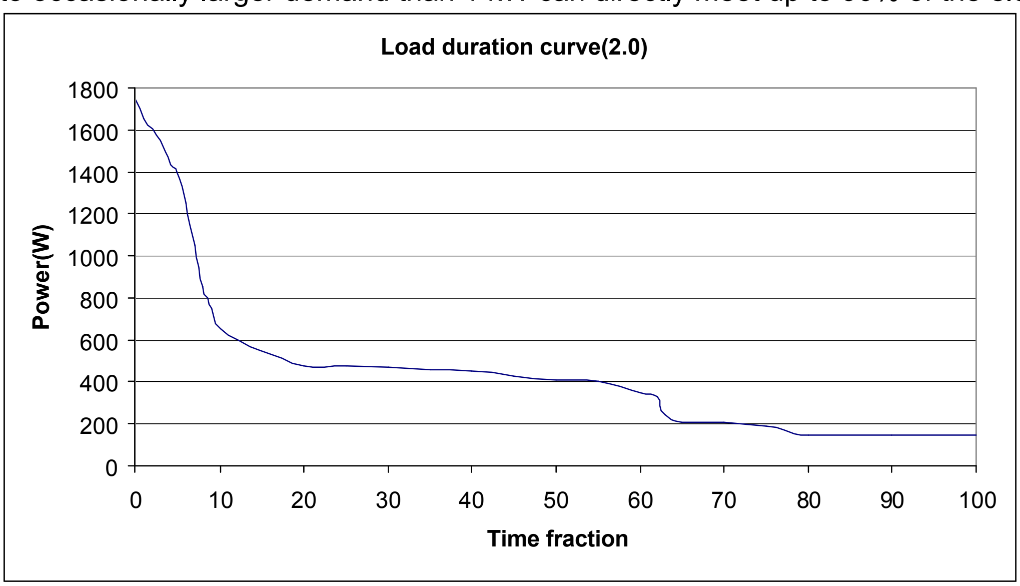


Figure 16: Typical household electricity demand distribution in Spain.

3.5.5 Feed-in tariff and subsidies

The Spanish government recently published Royal Decree 661/2007 (May 25th, 2007), which established a revised tariff scheme for renewable energy and cogeneration projects. This new decree replaces Royal Decree 436/2004.

This Royal Decree regulates the purchase of surplus electricity supplied by fuel cell systems to the distribution company at a price of 0.1204 €/kWh.

Table 30 gives an overview of the average feed-in tariff and subsidies for renewable energy in Spain.

RD 661/2007 provides that wind energy generators can choose between selling electricity, for periods of at least one year, at a regulated price set by Royal Decree or at market prices plus a premium.

Fixed Tariff. The price is set at 73.2 €/MWh (2007 base price), for wind during the first 20 years plus complements reducing to 61.2 €/MWh (2007 base price) after 20 years of operation.

Market Price & Premium: The market tariff option is the sum of the market pool price, plus a market option premium, plus reactive energy remuneration, less any imbalance charges. The market option premium is 29.3 €/MWh (2007 base price), only during 20 years. The market tariff option is subject to a cap and floor mechanism ranging between 71.3 and 84.9€/MWh (2007 base price).

In the wind offshore case the maximum market option premium will be 84.3 €/MWh with a cap in the market tariff of 164 €/MWh.

The fixed tariff option, market option premium, market tariff cap and floor and the reactive energy remuneration are escalated annually by IPC (Spanish consumer price index) less 0.25% until the end of 2012 and IPC less 0.5% thereafter.

Table 30: Overview of feed-in tariff and subsidies for renewable energy in Spain.

Renewable energy option	Tariff/subsidy	Unit
Electricity feed-in tariffs	0.0293	€/kWh
Subsidy electricity from wind energy	0.0732	€/kWh
Subsidy electricity from biomass	0.10-0.15	€/kWh
Subsidy electricity from biogas	0.05-0.13	€/kWh
EU subsidy for cultivation of energy plants on set-aside lands	45	€/ha

The wide range in biomass and biogas subsidies are due to biomass and biogas can be produced from a variety of feedstock, and depending on this the subsidies are different according to the Royal Decree 661/2007.

The spot market price for electricity in Spain is shown in Figure 17. It shows that within one day the electricity price variation is a factor 2.

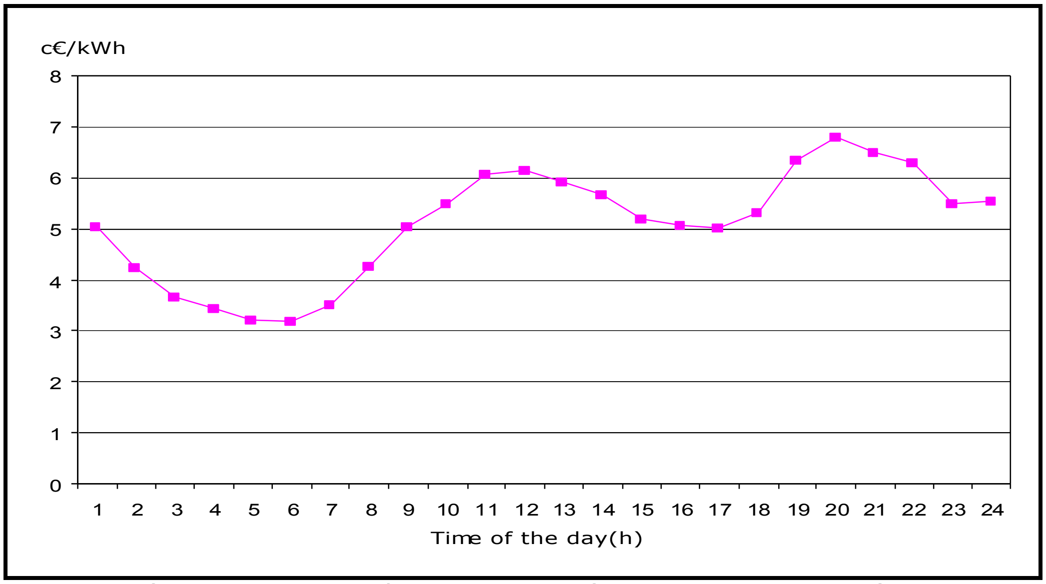


Figure 17: Spot market price for electricity in Spain, January 2007. Source: REE

3.5.6 Regulations for small-scale CHP and hydrogen

The correct grid integration of wind power is one of the most important aspects in the future development of wind energy. In many places, not only in Navarra but in Spain, the wind resource is high, being able to install more power, but the network capacity limits that. Indeed, data show that the average size of wind turbine of more than 70% of the machines in Spain is below 1 MW. These two factors point as solution a repowering of wind farms with bigger wind turbines to increase the power generation and profit the wind excess to produce hydrogen. The Navarra region will be able to use hydrogen as fuel to provide heat and electricity to the houses.
The Royal Decree 661/2007 published in ay 2007 regulates the purchased of surplus electricity supplied by fuel cell systems to the distribution company at a price of 0.124 €/kWh, quite higher that the previous tariff (approx. 0.07 €/kWh). This would be a benefit to the end users to install this technology in their household.

Nowadays in Spain there is no regulation about hydrogen and fuel cell.

3.5.7 Wind energy supply/installations

In 2006, 38 wind farms worked, with more than 1000 wind turbines. The wind power installed in Navarra (916.8 MW) was 1.8 % of the European Union (48627 MW) and 7.9 % of the wind power installed in Spain (11600 MW).
In 2006, 69% of the total electricity consumed in Navarra came from renewable energies (76 % from wind power).
In Navarra there are more than 3.500 people working in the wind energy sector.

The cost of off-peak electricity that can be used for the electrolyser is estimated as 0.0402 €/kWh. The price is an average with the cheapest 8 hours, according to Figure 17.

3.5.8 Present plans for FCHS and key actors

Two communities, Sarriguren and Tudela in Navarra are interested in housing fuel cells for households in the near future. A demonstration project for fuel cells in households should be for maximum 20 households per community. The visibility of the demonstration is important for these communities.

The key actors in Spain are:
The Navarra region in the north of Spain is interested in the initiative for approx. 20 dwellings in Sarriguren and/or Tudela.
Wind energy sector:

- Acciona Windpower
- Eólica Navarra, S.L.
- Desarrollo de Energías Renovables de Navarra (DERSA).
- Ecotecnia
- Gamesa eólica
- Ingeteam, S.A
- LM composites
- M Torres

Centro Nacional de Energías Renovables (CENER) – Renewable Energy National Centre

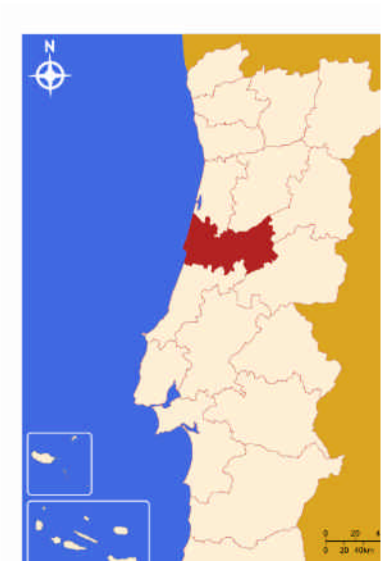
3.5.9 Main barriers

- The cost of fuel cell household systems is still too high for commercial application.
- The safety of a hydrogen grid into houses is not yet regulated well; e.g. standard odorants for natural gas are not suited for hydrogen because the low density of hydrogen causes separation of odorant and hydrogen.
- 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.
- Competing technologies are solar energy systems for households. In 2005 Spain became the first country in the world to require the installation of photovoltaic electricity generation in new buildings, and the second in the world to require the installation of solar hot water systems. The photovoltaic system can already provide electricity at the house and the solar hot water system prevents the use of the heat from the fuel cell.

3.5.10 Contacts

Pedro Sánchez , Ajusa . Fuel Cell Manufacturer
Natallio Peláez Muñoz , Schunk Ibérica, S.A. Fuel Cell Manufacturer
Javier Urra*, MesDea. Electrolyser Manufacturer
    *We have made the contact through Zertan, one of its sales divisions in Navarra
Oriol Martinez*, Claind. Electrolyser Manufacturer
    *We have made the contact through Teknokroma, one of its sales divisions in Spain
Jesus María Iriondo*, Accagen. Electrolyser Manufacturer
    *We have made the contact through Maser, one of its sales divisions in Spain
Jesus Izquieta, Praxair. Supplier of hydrogen
Miguel Angel Pascual, Miyabi. Household promoter.

3.6 Coimbra, Portugal



3.6.1 Description of Coimbra

Coimbra is situated in the middle of Portugal as can be seen on the map. Coimbra is one of the most important urban centres of Portugal after the much larger Lisbon Metropolitan Area and Porto Metropolitan Area conurbations, and plays a role as the chief city of the central part of the country. The next tables are for the Portugal as a whole. Whenever specific information for Coimbra region is available this will be provided.

Table 31: Characteristics on houses and inhabitants for Portugal and Coimbra

Characteristics	Portugal	Coimbra region
Inhabitants (*1000)	10566	148
Houses (*1000)	3651	
Inhabitants/km^2	114	129

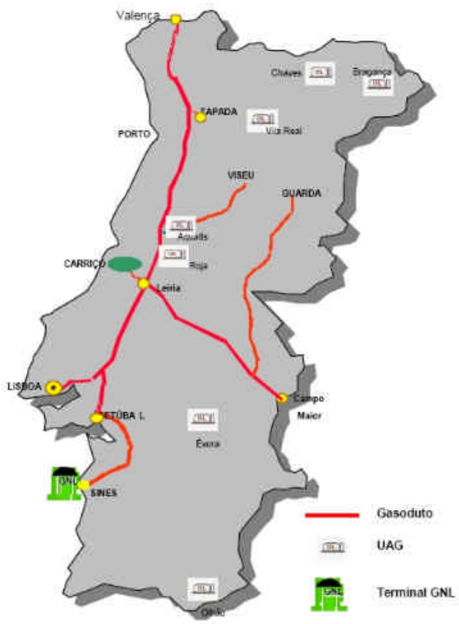
3.6.2 Energy infrastructure for heat and electricity

In Portugal the natural gas grid only comprehends one part of the country and it is predominant in the littoral and only in the urban areas. Figure 18 shows the natural gas pipeline distribution in Portugal. Due to this fact and due to the high price of natural gas to the end user the space heating in Portugal is almost only electrical. With regard to electricity Table 30 shows that almost all houses in Portugal are connected to the electric grid, the few cases were this does not happen are related with extreme remote locations. In the end of 2004, about 45.1 TWh of electricity were produced in Portugal, from these about 34.1 TWh were produced in thermoelectric power plants that operates with coal and natural gas. The electric generation from renewable sources amounts about 11 TWh, of which 10.1 TWh are produced from hydroelectric, 0.8 TWh from wind, 0.1 TWh from geothermic and 0.03 TWh from photovoltaic. The total energy production from renewable is a little greater if we take into account that about 5.6 TWh are produced in cogeneration units, which in some cases are running on renewable energy sources, especially biomass. In 2004 the installed production capacity consisted of 7.44 GW of thermoelectric power plants, 4.62 GW from hydroelectric power plants and 1.04 GW from wind, geothermal and photovoltaic power plants.

In 2005 the total energy production increased about 3.4 TWh, in part due to the increase of the total production capacity of 0.8 GW, which was mainly due to the increase of the production capacity of wind. In 2006 the energy production was 49.9 TWh, having increased by 1.4 TWh relatively to 2005, This increase was due to the increase of production capacity of wind power that has been expanded in the last few years, and also due to the increase of production in the hydroelectric power plants.

Table 32: Energy distribution infrastructure to houses in the Portugal

Energy infrastructure to houses	Portugal
Electricity grid	99.99%
Natural gas grid	In the rural areas there is not a NG grid, Only in the urban areas.
District heating grid	Only in a very limited area: In the Lisbon Expo 98 area



Fonte: Transgás

Figure 18: Natural gas pipeline distribution in Portugal.

3.6.3 Household energy system demand

Table 33 presents figures for the energy consumption in Portuguese households. The total electricity consumption of a household in Portugal, with high electricity needs, amount to around 3500 kWh 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 last for 4 months and the most important energy sources used for heating (space and hot water) 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 to 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.

Table 33: Energy consumption of households in Portugal.

Consumption patterns for households	Portugal Average household	Unit
Electricity consumption	3574	kWh/yr
Energy consumption for space heating	980 (only electrical)	kWh/yr
Energy consumption for tap water	1450	kWh/yr
Energy consumption for cooking	n.a.	kWh/yr

3.6.4 Household cost for heat and electricity

Table 34 gives an overview of the average energy prices for Portuguese household in 2007.
Heat for space heating is mostly produced through electric equipments. In the littoral cities, tap water is produced from natural gas because the natural gas pipeline is available there. In other locations the tap water production is mainly produced from burning butane gas or wood in boilers.

Table 34: Energy prices including taxes for households in Portugal.

Energy prices for households	Portugal	Unit
Electricity price (Eurostat 2007)	0.0150	€/kWh
Natural gas price (Eurostat 2007)	0.050	€/kWh
Energy price for space heating	0.06	€/kWh
Energy price for tap water	0.06	€/kWh

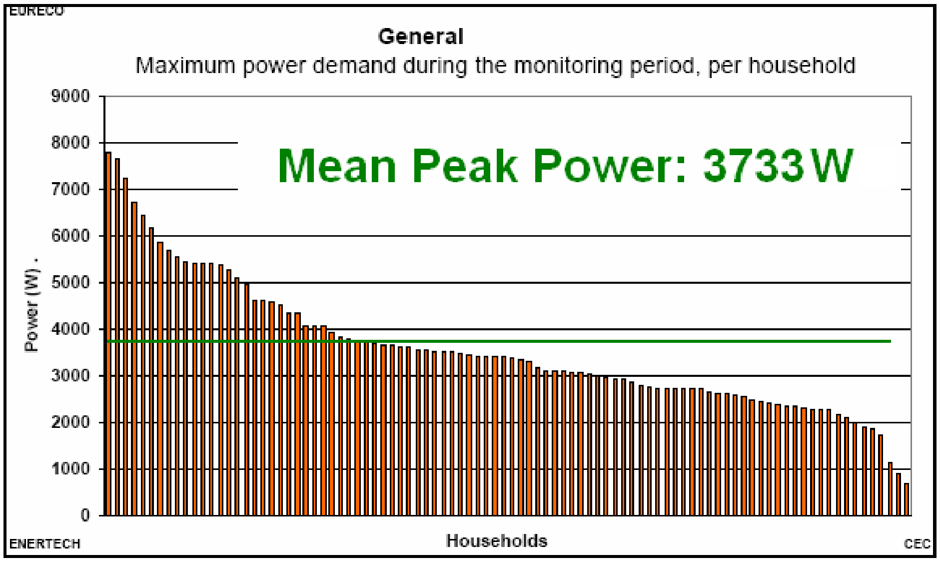


Figure 19: Power distribution for households in Portugal.

In Portugal the electricity consumers can chose from two different electric tariffs, the single tariff where the price of electricity is the same all over the day and with a small increase of the price in the fixed tariff, for contracted power and the day and night tariff which has a lower price during the night.
The electricity prices depend on the time of the day, as can be seen in Figure 20.

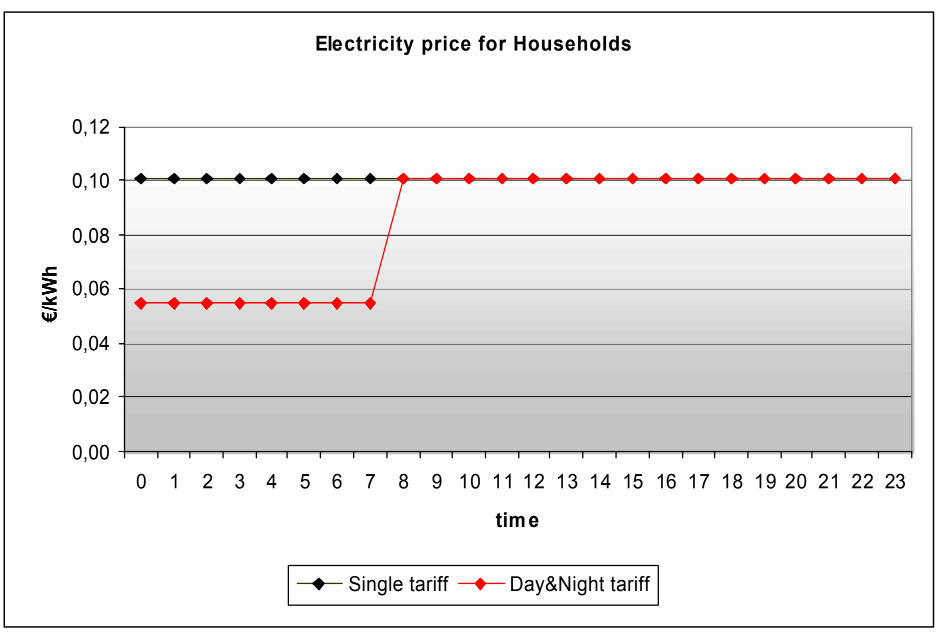


Figure 20: Electricity prices for households in Portugal.

3.6.5 Feed-in tariff and subsidies

Table 35 gives an overview of the average feed-in tariff and subsidies for renewable energy in Portugal till 2005.

Table 35: Overview of feed-in tariff and subsidies for renewable energy in Portugal;.

Renewable energy option	Tariff/subsidy	Unit
Electricity feed-in tariffs	0.20 – 0.35	€/kWh
Subsidy electricity from wind energy	0.09	€/kWh
Subsidy electricity from biomass	0.105	€/kWh
Subsidy electricity from biogas	0.105	€/kWh
EU subsidy for cultivation of energy plants on set-aside lands	45	€/ha

In 2001, a 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.

Table 36: CHP technologies purchase rates in Portugal (feed in tariff)

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

More recently, a new Decree Law (Decree nº 363/2007) for micro generation was published on November 2, 2007. Decree nº 363/2007, brings new opportunities for selfproducers based on renewable sources. 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 150 kW. This Decree Law stimulates the production of electricity from micro generation units, which can be made from photovoltaic panels, mini-wind turbines, cogeneration 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 for the first 10 MW of installed power connected to the grid, guaranteed during the first five years of interconnection. After this period, the tariff in force will be applied. For each additional 10 MW of installed power connected to the grid, this tariff will decrease by 5%. One disadvantage of this law is that the self-producer can only sell power to the grid if he is self sufficient, that means producing the electrical energy he needs. Only excess energy can be sold to the grid. With this law, the Portuguese government target is to have a total power of 165 MW that is produced from micro generation till 2015. In the case of the micro generation units other then co-generation from Biomass, the producers will have to install solar panels with at least $2m^2$ of area for hot water production.

The feed-in tariff, Table 37,will depend on the type of renewable energy source used being:

Table 37: Feed-in tariff from November 2007

Type of technology used	€/kWh
Solar and fuel cells with H_2 from solar	0.65
Wind and fuel cells wih H_2 from wind	0.456
Hydro and fuel cells with H_2 from hydro	0.196
Biomass co-generation and fuel cells with H_2 from biomass	0.196

3.6.6 Regulations for small-scale CHP and hydrogen

Portugal has an aggressive strategy to increase the share of renewable energy to 39% by 2010. Specific targets have been set by the Ministry of Economy for a range of technologies.
Fuel cells still do not obtain particular regulations from the Portuguese government. However there are some regulations and incentives to promote renewable energy production, micro-generation (with fuel cells, for example) and co-generation. Feed in tariffs are the main incentive for renewable and co-generation development. The most important regulations are presented below:

National Strategy for Energy: This document released in 2006, outlines the objectives of the energy strategy for Portugal, with three main axes: i) ensure energy's security of supply, ii) stimulate and foster competitiveness and, iii) ensure the environmental integration in the whole energy process. The main measures presented go in the direction of liberalization of the energy market, major role for renewables, promotion of energy efficiency, reorganization of taxes and incentives system and innovation on energy.

Operational Programme for Science and Innovation – POCI 2010: POCI is a programme aiming the promotion of science and innovation, namely through the funding of scholarships, research projects and institutions.

Law-Decree that fulfils a set of measures concerning renewable energies predicted in the National Strategy for Energy, established in the Resolution of the Council of Ministers no. 169/2005, dated 24th October:

This Law-Decree fulfils a package of measures set in the National Strategy for Energy, concerning renewable energies and aiming at facilitating and speeding the licensing procedure of this kind of energies. This decree foresees the following measures:

- The criteria for the remuneration for electricity are adjusted for water power, Photovoltaic Solar Energy, in particular of microgeneration, and solar-thermoelectric power, biomass, biogas and **for innovative technologies** like wave power;
- Special predictability conditions are created for the power attribution tenders;
- The installation of overequipment is made possible in wind power plants with license or in licensing procedure, providing that the installed aero generators are modernised and that the rate has a discount.
- This measure is a way to develop wind power, since the existing infrastructure is therefore used and both the environmental impact and licensing and building times are decreased;
- It also sets a time limit applicable to the extension of the wind power plants under construction, trying this way to reduce the existent asymmetries between the former and the actual legislation
- A set of measures is implemented to simplify and speed up the licensing procedures of renewable power installations.

3.6.7 Wind energy supply/installations

By the end of 2006 1716 MW of wind power is installed in Portugal. By the end of 2010 Portugal will have installed and operating about 5100 MW of wind turbines, 40% of which will be installed in Coimbra Region. Table 39 presents the total wind power that will be installed till 2010 in Portugal.

Table 38: 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%**

There is a high potential for the installation of more wind power in Portugal; wind resource is high and economically attractive because of the government support, but there are some constraints, in particular grid interconnection issues. The integration of wind power into the grid is the most important constraint to the development of future wind power, because of the limited reception capacity of the network. About 400 M€ 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.

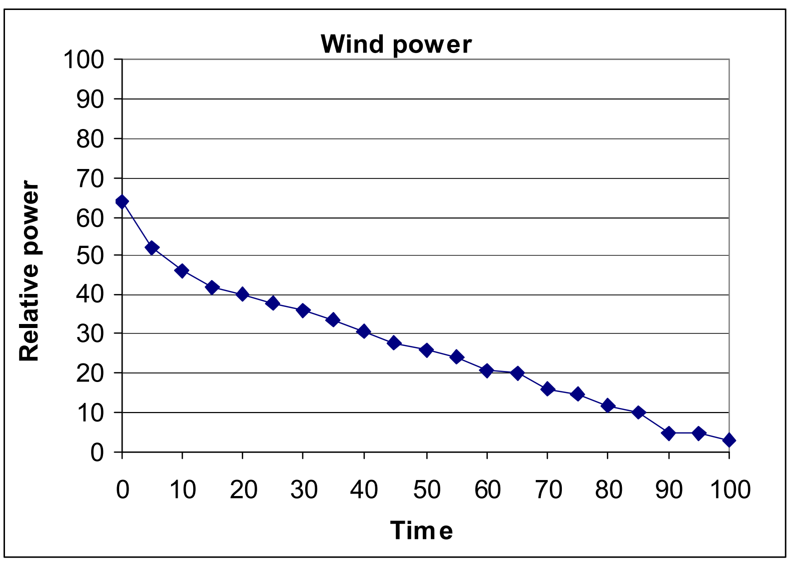


Figure 21: Relative national wind power electricity production distribution for Portugal.

The cost of off-peak electricity that can be used for the electrolyser is estimated as 0.052 €/kWh.

3.6.8 Present plans for FCHS and key actors

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 key actors in Portugal are:

- Energy supply (potential suppliers of the primary energy source): Wind power plants
- Energy transformation (potential suppliers and owners of the equipment producing and distributing biogas, alcohol or hydrogen): Biogas companies, sewage treatment plants, urban solid waste, Wastewater treatment plants, animal farms, food industry.
- Energy end-use (potential end-users of biogas, alcohol or hydrogen, potential users of heat): Households
- Energy buyers: Electric utility EDP
- Ancillary Services Buyers (TSOs buying regulating power, and voltage and frequency regulation): National grid REN
- Potential users of other by-products: Glass and chemical industry, Urban transportation
- Authorities setting framework conditions (national, regional, country, municipal): Government

3.6.9 Main barriers

The main barriers identified are:

- There is no legislation on hydrogen storage and transport.
- Nowadays there is no excess wind power in Portugal, especially because the new government strategy of developing hydro power plants using excess wind power;
- No H_2 network, H_2 storage and transportation is a major concern because of security issues and also because of the price of the technology;
- Remote location of wind power plants, whose access is quite difficult;
- Price of electrolyser;
- Price of fuel cells;
- Low system efficiency cascade (full-cycle efficiency is estimated to be quite low);
- Feed in tariff (0,20-0,30 €/kWh);
- Very low government/stakeholders will;
- Lack of financial incentives for households
- Residential users are not keen on paying large sums of money for green power;

Other applications that use large amounts of H_2 are the glass industry and the chemical industry.

3.6.10 Contacts

- Paulo Rui Carvalhinho Oliveira, Câmara Municipal da Lousã, Municipality
- Mário Pelicano, Bascol, Construção Civil S.A., Building Company
- Vasco Silva, SRE – Fuel Cells, Fuel Cell Manufacturer
- Sumrit Jeang, Siam Water Flame, Electrolyser Manufacturer
- Max Flint, Teledyne Energy Systems Inc., Electrolyser Manufacturer
- Tucker Ruberti, IdaTech, Fuel Cell Manufacturer
- Ralph Schanz, Heliocentris, Fuel Cell Manufacturer
- Linde Gas, Hydrogen Storage Systems

- Daniele Todescato, Elettronica Todescato s.r.l., Electrolyser Manufacturer
- Marketing Department, Ballard Power Systems, Fuel Cell Manufacturer
- Volker Nerlich, Hexis AG, Fuel Cell Manufacturer
- Carlos Velasco, AJUSA, Fuel Cell Manufacturer
- Gus Block, Nuvera Fuel Cells, Fuel Cell Manufacturer
- David Paul, UTC Power, Fuel Cell Manufacturer
- Carlos Lopes, Air Liquide - Portugal, Hydrogen Storage and Distribution Systems
- Arjen Teunissen, Plug Power, Fuel Cell Manufacturer

4 Summary and evaluation of the regional markets

4.1 General

The RES fuel cell household system considered in this project is a hydrogen based low temperature PEM fuel cell which has a power range of 0.5-1 kW electrical and 0.5-1 kW thermal. In this way an aggregated market with nearly identical units can be obtained. These systems will be preferably located in new dwellings where the heat demand is low.

The legislation for the use of hydrogen and fuel cells in household in the nations concerned is in development. The use of hydrogen in households still has safety concerns like detection of hydrogen leaks. The status of the legislation is shown in Appendix A.

The number of communities and regions that are interested in demonstration of RES-FC Market systems is still small and also the amount of units identified based on existing plans, initiatives and intensions. Until now 1200 potential units have been identified in the period up to 2010. The potential units are here defined as the present plans for fuel cells for households in order to come to an aggregated market. The aggregated market of 3000 houses in the next years therefore needs also the development of new markets after a successful demonstration of the technology.

An overview of the cost of the renewable energy for the cases and the regions considered is provided in Table 39. This table shows a large variation in the cost of the fuel for the different regions. The feed in tariffs and subsidies have been provided for the different routes and regions and are shown in Table 40. For wind energy subsidies vary greatly from 0.0134 €/kWh in Denmark to 0.09 €/kWh in Portugal.

The biomass route is not yet established for methanol production. Methanol is a commodity produced from natural gas. In the Netherlands biomethanol from glycerine as by-product from the biodiesel fabrication is produc4ed. Ethanol reforming is not yet an issue.
Biogas can be upgraded to natural gas quality and fed into the natural gas grid. This requires many process steps. For both biogas and biomass the supply is in time uncoupled from the fuel cell.
For the excess wind route, the electrolyser and the fuel cell should not be operated at the same time. Economical optimisation of the operation of combination of electrolyser/fuel cell will be established in work package 4.

Table 39: Cost of supply of renewable energy

WP2: Cost of supply	Fuel	Transport	Tax	Total	Power level	Remark
	[€/kWh]	[€/kWh]	[€/kWh]	[€/kWh]	[kW]	
Fuel for biogas (maize etc)						
Jutland, DK	n.a.	0.16[€/km/m^3]	n.a.	0		36 PJ available
Baden-Württemberg, DE	0-0.03	0.01-0.03	0.01	0.02-0.07	500	
Biomass for (m)ethanol						
Jutland, DK			0	0.017		Straw delivered at factory
Baden-Württemberg, DE	0.05	0.01	0.01	0.07		FNR: Biokraftstoffe
Reykjavik, Iceland	0.09	0.02	n.a.	0.11		Liquids from FT
Excess electricity from						

wind						
Jutland, DK	0.031	0.007	0.024	0.062	3150	off-peak electricity
Schleswig Holstein, DE	0.050	0.000	0.056	0.106	1500	Electrolysis at wind farm
Friesland, NL	0.029	0.020	0.010	0.059	1000	off-peak electricity
Navarra, ES	0.040			0.058		off-peak electricity
Coimbra, PT	0.048	0.057	0.005	0.110		off-peak electricity

4.2 Regions

In Denmark the installed wind energy capacity can even exceed the national electricity demand at certain times. Electricity grid stabilisation is a concern and a possible solution is conversion of electricity to hydrogen. Forcing electricity firms to have a certain amount of wind turbines installed stimulated wind energy in Denmark. The feed-in tariff for wind energy is low in Denmark compared to other countries, which means that practically no privately owned wind turbines are installed and the installed capacity has stayed constant over the last years. The community of Herning is interested in building a district with 200 houses that use hydrogen and fuel cells and 200 more units in Nolsoy, Sonderborg and Nakskov. Upgrading of biogas to natural gas conditions is possible.

In North-Germany regions like Schleswig Holstein with excess wind energy exist and a possible solution is conversion of electricity to hydrogen. Biomass conversion to (m)ethanol is not yet foreseen in Germany. Biogas is used in MCFC plants for CHP at 250 kW level. Biogas itself is not yet easily adaptable to hydrogen fuelled fuel cell CHP for households. Furthermore several locations exist where biogas is upgraded to natural gas quality and fed back into the natural gas grid. Using green gas certificates, this upgraded biogas can be attributed to fuel cells running on natural gas. The plan is to have 450 fuel cell CHP systems for households by 2010, 2.250 units by 2012, and 72.000 units/yr by 2020, spread over Germany.

Iceland is not in favour of methanol or hydrogen based fuel cell systems for residential applications since their geothermal heating and hydropower are renewable energy sources that already supply most of the energy for households. However for 100 recreational houses direct methanol fuel cell systems will be considered.

In the Netherlands the communities Leeuwarden (Friesland) and Arnhem support the initiative for the combination of renewables and fuel cell systems because they promote the reduction of green house gasses and when they are the first with such a demonstration they also improve their image. For cost reasons the demonstration size has to be < 20 houses. In Arnhem a citizen initiative for renewable energy with hydrogen as buffer/energy carrier is started for 138 existing dwellings and 150 new dwellings. In the Netherlands no excess wind energy is available until 2020.
Nuon ordered 50.000 high temperature (SOFC) fuel cell household systems to be fuelled by natural gas. The delivery starts at the end of 2009, if the performance targets are met, with a rate of 10.000 units/year. For the production a new factory will be built.

In Spain the Navarra region has excess wind energy available because of the weak electricity network and a possible solution is conversion of electricity to hydrogen. The legislation for solar collectors for new dwellings interferes with the heat supply by the fuel cell system. The fuel cell system will probably be controlled by the heat demand. The communities Sarriguren and Tudela are interested in fuel cells for households (10-20 dwellings).

In Portugal the Coimbra region is of interest with approximately 10 dwellings since it has a potential large wind energy capacity with a weak electricity network. The space heating requirements in Portugal can be met by 20% of the average electricity demand for households. The fuel cell system will probably be controlled by the heat demand which may is these countries result in low operating hours.

4.3 Performance indicators

The potential regional information is condensed in Table 40, and compared to the performance indicators in order to see whether in the near future the conditions for the markets are in place. The performance indicators are:

- Need of RES integration; the question is answered if there is a need find other processes or applications for the renewable energy supply than used today, since there is or becomes too much of this energy supply.
- Number of end users; the number of fuel cells for household systems identified in projects in the regions up to the year 2010.
- Infrastructure; the length of H_2 pipelines in the country (only industrial pipelines exist)
- Subsidy; the amount of subsidy in the country for the specific technology
- Feed-in tariff; the electricity feed-in tariff in the country for the specific technology
- Supplier RES/FC; are there suppliers for the renewable energy system/fuel cell system in the country. Too many suppliers will make cost reduction by mass fabrication difficult.

The main performance indicator is the need of RES integration, since that determines if alternative processes or applications are required. The cost of the FCHS technology is still too high. If the market conditions are in place this means that for these regions a market pull can develop.

Table 40 shows that market conditions for the regions can be in place if excess wind energy exists. For Navarrra and the Coimbra region the heat demand is low and therefore sufficient utilisation of the heat from the fuel cell installation is questionable. This needs to be investigated further. For the Netherlands there is no excess wind energy expected until 2020.

Biogas installations are nowadays equipped with a gas engine that provides electricity and heat. Upgrading of biogas to natural gas conditions and injection into the natural gas grid is another option that provides numerous uses of the biogas. It also requires many process steps.

Biomass conversion to (m)ethanol otherwise than by simple fermentation to ethanol is still under development. The use of (m)ethanol as fuel for residential fuel cell systems, either directly or by reforming is not foreseen in the near future.

The main barrier that needs to be levelled for the regions where the conditions are not in place is to provide a competing economical solution compared to other applications or technology.

Table 40: Performance indicator for the regional markets

Regional markets	*Performance indicator*	*Need of RES integration*	*End-users*	*FCHS End-users*	*H_2 Infra-structure*	*Subsidy*	*Feed-in tariff*	*Supplier RES/FC*	*Conditions in place*
Region	**Technology**	**Technical**	**2010**	**2020**	**km**	**€/kWh**	**€/kWh**	**X = yes 0 = no**	
Jutland, DK	Biogas	**no**					**0.08**	**X/X**	**no**
Jutland, DK	Biomass	**no**	**400**		**no**	**350 €/ha**		**X/X**	**no**
Jutland, DK	Excess wind	**yes**				**0.013**		**X/X**	**yes**
Baden-Württemberg, DE	Biogas	**no**					**0.08 - 0.21**	**X/X**	**no**
Baden-Württemberg, DE	Biomass	**no**	**450**	**72000 (DE)**	**340 (DE)**	**350 €/ha**		**X/X**	**no**
Schleswig Holstein, DE	Excess wind	**yes**					**0.08 - 0.09**	**X/X**	**yes**
Reykjavik, Iceland	Biomass	**no**	**100***		**no**			**X/0**	**no**
Friesland, NL	Excess wind	**after 2020**	**300**	**>50000 (NL)**	**240 (NL)**	**0.028**	**0.04**	**X/X**	**no**
Navarra, ES	Excess wind	**yes**	**20-40**		**no**		**0.063**	**X/0**	**yes/no? (heat)**
Coimbra, PT	Excess wind	**yes**	**10**		**no**		**0.09**	**0/0**	**yes/no? (heat)**
Total			1300	>132000	580				

* For Iceland the fuel cell type foreseen is the DMFC (direct methanol fuel cell), which does not contribute to the aggregated market for cost reduction.

These 1300 fuel cell systems for the end-users by 2010 consist of concrete plans for 400 systems, targets for 650 systems, inhabitant interest for 300 systems and community interest for 50 units.

The 10.000 high temperature fuel cell household units ordered for the Netherlands in 2010 are not in the table for the 2010 end users since these systems can not be part of the aggregated market for the systems discussed in this project. The 50.000 high temperature fuel cell household units for end users in the Netherlands will be reached in 2014.

5 Conclusion

The description and evaluation of the 10 potential markets in 7 regions is performed.
For the period up to 2010 an aggregated market of 1200 households are identified that have plans for hydrogen based residential fuel cell systems. For the aggregated market of 3000 hydrogen based fuel cell systems in the next years therefore the plans and targets need to develop into real initial customers in order to reach the objective of accelerating the introduction of RES-FCHS systems. The plan for Germany is to have 2.250 fuel cell CHP systems for households by 2012, and 72.000 units/yr by 2020. In the Netherlands 50.000 natural gas based high temperature fuel cell household systems are ordered by Nuon, starting at the end of 2009 with a rate of 10.000 units/year.

The cost of the fuel cell household system is too high; one of the objectives of this project is too lower the cost of the system by combining markets for increased cost reductions.

Legislation of hydrogen systems in households are still absent; this issue should be resolved in international cooperation.

The need of renewable energy integration is considered the main parameter for determination whether favourable market conditions exist. At this moment only excess wind requires alternative solutions for use of electricity in order too increase its market share in electricity production for some of the regions considered.

6 References

[1] G.J. Kraaij; RES-FC Market Status and cost of the technology options; 7.0281-06GR001; October 2006.

[2] DIAS report: Report from the Danish Working Group on the Co-existence of Genetically Modified Crops with Conventional and Organic Crops. Ministry of Food, Agriculture and Fisheries; Danish Institute of Agricultural Sciences; “Plant Production” no. 94, November 2003; ISSN 1397-9884.

[3] Krish K., Augenstein D., Batmale J.P., Benemann J., Rutledge B., Salour D.: Biomethane from Diary Waste. A Sourcebook for the production and use of Renewable Natural Gas in California. Prepared for Western Dairymen Michael Marsh, Chief Executive Officer; funded in part through USDA Rural Development, July 2005.

[4] Jensen J.K., Jensen A.B.: Biogas and Natural Gas Fuel Mixture for the Future. 1st World Conference and Exhibition on Biomass for Energy and Industry, Sevilla, 2000.

[5] Jensen F., Funktionschef, DONG Distribution; personal communication, 2006.

[6] The Danish Energy Authority: Heat Supply in Denmark – Who What Where and Why, January 2005; ISBN 87-7844498-3.

[7] Josart J.M.: *Boosting Bioenergy in Europe*. World Bioenergy Conference & Exhibition, Jonkoping, Sweden, 2006.

[8] Private communication Mr Grubel from Vattenfall.

[9] The German national development plan (Nationaler Entwicklungsplan), Version 1.1 of July 19th, 2006

Appendix A Status of legislation in Europe by February 2007.

The status of the legislation can be found at http://www.fuelcellstandards.com

C.	Europe		
	C.1	British Standard (BS)	
		BS EN 50073 Guide for selection, installation, use and maintenance of apparatus for the detection and measurement of combustible gases or oxygen	British Standard. Approved by CENELEC in 1998. (E.U. standard)
		"industry/government working group" Installation Guide for Hydrogen Fuel Cells and Associated Equipment	draft in progress
	C.2	CEN/CENELEC	
		CEN/CENELEC Fuel Cell Gas Heating Appliances	E.U. Standard draft in progress
		CEN/TC19 EWG on Fuels for Fuel Cells	E.U. Standard committee forming
	C.3	Deutscher Verein des Gas und Wassertaches (DVGW)	
		VP119 Preliminary Basic Rules for Testing Fuel Cell Appliances - 70 kW	DVGW Standard published Oct. 2000
	C.4	European Integrated Hydrogen Project (EIHP)	
		EIHP Work Package 1 Overall Coordination	
		EIHP Work Package 2 Refueling Station	
		EIHP Work Package 3 Refueling Interface	
		EIHP Work Package 4 Vehicles	
		EIHP Work Package 5 Safety	
		EIHP Work Package 6 Links "EU-USA" Cluster Activities	
	C.5	European Standards (EN)	
		BS EN 50073 Guide for selection, installation, use and maintenance of apparatus for the detection and measurement of combustible gases or oxygen	British Standard. Approved by CENELEC in 1998. (E.U. standard)
		EN 62282-2:2004 Fuel Cell Modules	IEC Standard adopted by E.U.
		EN 62282-3-2:2006 Test Method for the Performance of Stationary Fuel Cell Power Plants	IEC Standard adopted by E.U.