Regional markets of RES-fuel cell systems for households

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The scope of the proposed action is to make a contribution for changing the development of renewable energy sources (RES) fuel cell household systems (FCHS) from solely R&D to include also market development and in this way accelerate the development of the technology and its economic performance. The specific goal is to describe in a "catalogue" 10 regional markets for RES-FCHS with an aggregated market of more than 3000 RES-FCHS units to be realized in a nearby future. By cooperation between the regional RES-FCHS markets, the regional markets shall be used for driving down the costs of RES-FCHS to a level lower than 5000 €/kWe, e.g. by "pooling" of the regional markets to have a positive effect of scale. Lessons from the successful European technology and market development of wind turbines will be transferred into the RES-FCHS sector, making EU a driver of the global RES-FCHS development.

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I. Introduction

The aim of the EU-project "RES-FC Market" was 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 CO2 and other emissions related to energy use in households. For the successful of the market development it was 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 was 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 have been investigated that have been identified upfront as potentially interesting.

The main objective of the "RES-FC Market" was 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 would be generated to get FCHS developers to start producing systems in series.

This paper is a result of the research carried out for the RES-FC project by 12 participants from 7 different countries formed this consortium representing universities, research centres and developers of RES-FCHS systems, in particular: HIRC, DK; UoI, IC; ISR, PT; AAU, DK; CENER, SP; ECN, NL; IBBK, GR; Dong Energy, DK; IRD, DK; Dantherm A/S, DK; KBIZ, GR; BIC, PL;

Three different technological streams have been addressed in this project:

- Fuel Cells working with hydrogen produced from biogas;
- Fuel Cells working with hydrogen produced from biomass;
- Fuel Cells working with hydrogen produced from electrolysis using wind energy, especially "excess wind".

In Table I, the Project partners are discriminated by technology stream and geographic location.

According to the technology involved and the geographic location each partner developed a regional market development plan with the aim to promote the development of an European market for RES-FCHS, based on a trans-regional cooperation using the regional markets as stimulators.

The idea behind this transregional cooperation is to promote the technology and reduce the implementation costs to values lower than 5000€/kWel.

Ideally, cost reduction is expected to be achieved through the implementation of a RES-FCHS market with a minimum of 3000 units based on 10 regional markets of 300 units each.

TABLE I
PARTNERS DISCRIMINATED BY TECHNOLOGY AND GEOGRAPHIC LOCATION

Technology and Geographic location	Project partner
• Biogas	
Jutland, Denmark	AAU Esberj
Baden-Württenberg, Germany	IBBK
• Methanol/Ethanol - Biomass	
Jutland, Denmark	Dong Energy
Baden-Württenberg, Germany	KIBZ
Reykjavik, Iceland	University of Iceland
• Hydrogen – Wind energy	
Jutland, Denmark	HIRC
Schleswig-Holstein, Germany	KBIZ
North Friesland, Netherlands	ECN
Navarra & the Basque Country, Spain	CENNER
Coimbra, Portugal	ISR-UC

II. The 3 Technologic Options

Hydrogen is only an energy carrier and it can only be produced from primary energy sources. In this project, three primary energy sources have been investigated, which are:

- Organic matter suitable for biogas production;
- Biomass in general;
- Wind Energy, especially "excess wind".

In order to develop an aggregated market it is important to have some standard procedures and processes to convert the above mentioned energy sources into heat and electricity, and hence the following 3 standardised processes have been suggested:

Case 1: Biogas to CHP
Case 2: Biomass and Wind to CHP
Case 3: Only wind to CHP

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.

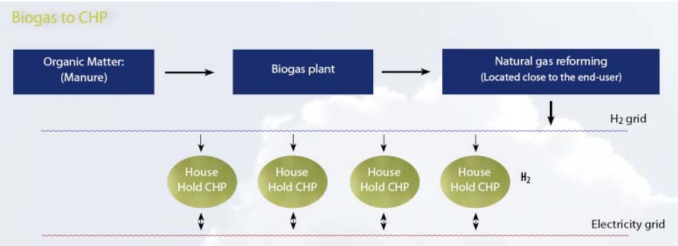

Figure 1 – Case 1 Biogas to CHP

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. Hydrogen 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 H2. 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.

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 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.

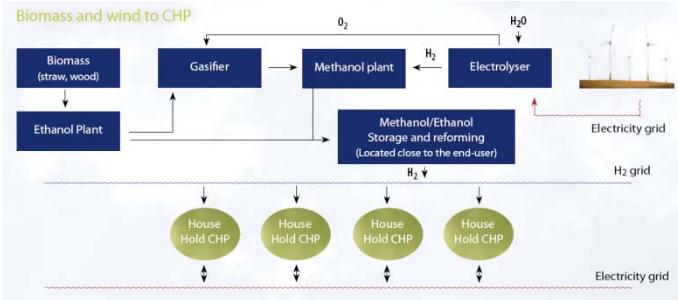

Figure 2 – Case 2 Biomass and wind to CHP

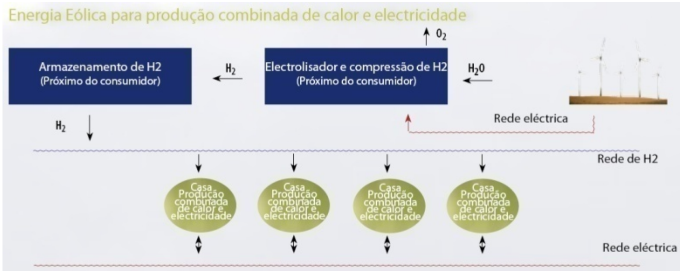

Figure 3 – Case 3: Only wind to CHP

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.

III. Fuel Cell Household System

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 considered. 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 kWe
- Fuel cell type: PEMFC
- Fuel type: pure Hydrogen
- Heating power: 0.5-1 kWe
- 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 and low electricity needs.

IV. Regional Markets

Jutland, Denmark

Jutland is the western continental part of Denmark. 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. 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.

TABLE II
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

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

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. Table III presents the energy distribution infrastructure to houses in Denmark.

TABLE III
ENERGY INFRASTRUCTURES TO HOUSE IN DENMARK

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

Table IV presents figures for the average energy consumption in Danish households.

TABLE IV
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

The main barriers for the development of the regional market development plan, based on wind energy, are:

- In spite of the price variations on the spot market, the differences are not sufficiently high to enable an economically feasible operation of the fuel cell system as a storage system.
- One has to operate at least 10 MW to operate on the Nordic market for power regulation.

Strategies to overcome the barriers:

- Introducing a pricing system corresponding to the system for solar cells will give a much better price for electricity sold to the grid. Buying electricity on the spot market while getting a much higher selling price would give an asymmetrical system though and some price distortion in favour of the RES FC owner;
- With Denmark's expansion of wind power, ways of integrating wind power is required. This opens a door for fuel cells and electrolysers.

The main barriers for the development of the regional market development plan, based on Methanol, are mainly economic.

Overcoming the barriers:

- It may be added that Danish consumers are already accustomed to having communal heat supply systems, so solutions need not even be in form of totally decentralised solutions in each dwelling. It may also include solutions for clusters of houses, which may bring the fuel cell and reformer costs down – at the expense of having to install a district heating network though;
- Such central plants will bring the cost down and make the systems more economically feasible though economy of scale and may also make accessing the power spot market and the regulating market more reachable, however some special incentives will still be required.

The main barriers for the development of the regional market development plan, based on Biogas, are:

- At an European level there are several barriers that need to be overcome, however some of those have already been overcame in Denmark during its gradual transition from a central energy system to a de-central energy system. This relates to issues like building permits and grid access which are not universally readily accessible in Europe.
- As opposed to the hydrogen cases, the low cycle efficiency is not an issue here as fuel cells are at least comparable to alternative engines and gas turbines in terms of efficiency – and will most likely in the future reach higher efficiencies than those systems.

Strategies to overcome the barriers:

- Attractive Feed-in tariffs are required to overcome the barriers;
- Lower VAT on renewable energy would favour biogas technology;

- Demonstration projects would show-case the technology and probably through further implementation drive down costs;
- Mandatory targets would also further the technology.

Schleswig Holstein and Baden-Württemberg, Germany

- **Region of Baden-Württemberg**

Baden-Württemberg is situated in the south-western part of Germany. Although it has a few multinationals, Baden-Württemberg's economy is basically dominated by small and medium sized enterprises. Many enterprises are considered innovative.

- **Region of Schleswig Holstein**

Schleswig Holstein is the northernmost federal state of Germany and is situated between Northern Sea and Baltic Sea.

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.

TABLE V
CHARACTERISTICS ON HOUSES AND INHABITANTS FOR GERMANY AND THE REGIONS SCHLESWIG HOLSTEIN AND BADEN-WÜRTTEMBERG

Characteristics	Germany	Baden-Württemberg	Schleswig Holstein
Inhabitants (*1000)	82315	10739	2834
Houses (*1000)	39754	4910	1380
Inhabitants/km^2	231	300	179

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. The coverage range of the electricity grid is very high and almost 100 % of all households are connected to it. Table VI presents the energy distribution infrastructure to houses in Germany.

TABLE VI
ENERGY INFRASTRUCTURES TO HOUSE IN GERMANY

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

Table VII presents figures for the average energy consumption in German households assuming 4 persons household.

TABLE VII
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

The main barriers for the development of the regional market development plan, based on methanol and wind energy in Germany:

- Ethanol and hydrogen should not be used for stationary applications; the fuels are too precious for this use and are better used in vehicles where options are more limited in contrast to stationary applications, where much less manageable energy resources may be tapped.
- A number of other barriers of a more technical nature are possible, especially: lifetime, robustness and costs.

Strategies to overcome the barriers:

- Fuels cells for household use will be competing with other uses of appropriate fuels but German energy plans include a large expansion of RES FC systems;
- Technical barriers in the form of lack of technical robustness are to be addressed through the German expansion plan.

Reykjavik and Western Fjords, Iceland

- **Reykjavik**

The Reykjavik area is situated in the southwest part of Iceland. 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.

- **Western Fjords**

In the Western Fjords, 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 VIII
CHARACTERISTICS ON HOUSES AND INHABITANTS FOR ICELAND AND THE REGION OF REYKJAVIK

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

In Iceland heating is supplied by geothermal energy. In the Reykjavik area all houses are connected to the central heating system. In the Western Fjords, most heating is done by grid connection. Geothermal heat provides 87% of the required heating. Table IX presents the energy distribution infrastructure to houses in Iceland.

TABLE IX
ENERGY INFRASTRUCTURES TO HOUSE IN ICELAND

Energy infrastructure to houses	Iceland

Electricity grid	99.99%
Natural gas grid	n.a.
District heating grid	2900 km

The main barriers for the development of the regional market development plan, based on methanol are:

- As the main part of Iceland is supplied with heating from geothermal sources, there is little need for any heat produced by RES FC fuel cells.
- Electricity is furthermore also of little concern as the country has good hydro electric resources.

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

TABLE X
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
Energy consumption for cooking	n.a.	kWh/yr

Strategies to overcome the barriers:

- The national ambition of lowering fossil fuel dependency gives the impetus to actually implement fuel-cells. While the policy is largely targeted at transport (vehicles and the fishing fleet) the policy will also create the infrastructure that will be a pre-requisite for using RES-FC systems;
- Analyses already show that hydrogen from electrolysis is feasible in Iceland;
- There is already a dedicated company - Carbon Recycling International - that will have an inherent interest in expanding its target group to include also residential consumers.

North Friesland, the Netherlands

Friesland is situated in the north of the Netherlands 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. Specific information on the number of new houses in districts with more than 200 houses is not available.

TABLE XI
CHARACTERISTICS ON HOUSES AND INHABITANTS FOR THE NETHERLANDS AND FRIESLAND

Characteristics	The Netherlands	Friesland
Inhabitants (*1000)	16334	643
Houses (*1000)	6967	275
Inhabitants/km^2	394	192
New/existing houses (%/yr)	1.03%	0.99%

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 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). Almost all houses in the Netherlands are connected to the electricity grid. Table XII presents the energy distribution infrastructure to houses in The Netherlands.

TABLE XII
ENERGY INFRASTRUCTURES TO HOUSE IN THE NETHERLANDS

Energy infrastructure to houses	The Netherlands
Electricity grid	>99.99%
Natural gas grid	97%
District heating grid	4%

Table XIII presents figures for the energy consumption in The Netherlands households.

TABLE XIII
ENERGY CONSUMPTION OF HOUSEHOLDS IN THE NETHERLANDS

Consumption patterns for households	The Netherlands Average household	Unit
Electricity consumption	3400	kWh/yr
Energy consumption for space heating	10600	kWh/yr
Energy consumption for tap water	3400	kWh/yr
Energy consumption for cooking	600	kWh/yr

The main barriers for the development of the regional market development plan, based on wind energy are:

- The production cost for electricity based on small-scale RES FC systems will be in the order of 0.31 € per kWh which is higher than the electricity cost for normal consumers including all taxes etc;
- The costs are closely linked to the low cycle efficiency and unit costs.

Strategies to overcome the barriers:

- It will not be possible to install RES FC systems within the next decade in the Netherlands as the costs are simply too high and the system too inefficient.
- In spite of this, there is some movement going on as indicated in the proposed activities in Leeuwarden and Arnhem.

Navarra, Spain

Navarra is situated in the north of Spain. 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.

TABLE XIV
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%

Almost all houses in Spain are connected to the electricity grid. 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. 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 XV presents the energy distribution infrastructure to houses in Spain.

TABLE XV
ENERGY INFRASTRUCTURES TO HOUSE IN SPAIN

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

Table XVI presents figures for the energy consumption in Spanish households.

TABLE XVI
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

Strategies to overcome the barriers:

- It is required to demonstrate to fuel-cell producers that residences are in fact a market niche;
- It is necessary to make an effort in R&D to improve efficiencies, reliability, lifetime, and materials performance;
- According to the households promoters, in Navarra would be more interesting to use a 1 kW_e + 3 kW_{th} CHP fuel cell;
- Increased Government support both in terms of legislative reform and financial support;
- It will be necessary a lot of dissemination activities about hydrogen technologies to encourage the concept of clean energy among the general public.

Coimbra, Portugal

Coimbra is situated in the middle of Portugal. Coimbra is one of the most important urban centres of Portugal after the largest Lisbon Metropolitan Area and Porto Metropolitan Area, and plays a role as the main city of the central part of the country.

TABLE XVII
CHARACTERISTICS ON HOUSES AND INHABITANTS FOR PORTUGAL AND COIMBRA

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

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. Due to this fact and due to the high price of natural gas to the end user the space heating in Portugal is most electrical. 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. Table XVIII presents the energy distribution infrastructure to houses in Portugal.

TABLE XVIII
ENERGY INFRASTRUCTURES TO HOUSE IN 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

Table XIX presents figures for the energy consumption in Portuguese households.

TABLE XIX
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

The main barriers for the development of the regional market development plan, based on wind energy are:

- As for all the other markets, the price is the main barrier to overcome – particularly combined with the low cycle efficiency and lack of heat demand due to a mild climate;
- With the Portuguese Government's decision to promote pumped hydro storage, presently there is no excess wind power to be utilised and the public support is also not sufficient to make the solution economically attractive.

Strategies to overcome the barriers:

- The largest construction company in the central region of Portugal has shown some interest in the project and in the RES FC technology, albeit, costs have been an issue;
- Government incentives are hence required to overcome the economic barrier met by private consumers or by building constructors;
- It is required to demonstrate to fuel-cell producers that households are in fact a large market in Europe;
- It is necessary to improve the fuel-cell technology in terms of costs, efficiency, reliability and life time.

V. CONCLUSIONS

General lessons learnt are that fuel cells are still an immature technology which stack lifetime has to be improved to increase the reliability of the FC and to achieve reasonable costs. In addition, there is a need for subsidies and for harmonized legislation among EU. To gather the 10 regional markets in order to push manufacturers to decrease the price was a great strategic idea, and manufacturers involved in the project were very interested in such interesting approach.

ACKNOWLEDGMENT

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