FC-EuroGrid

Executive Summary of Project Findings

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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Abstract

It has become apparent in the development of the Fuel Cell and Hydrogen Joint Undertaking (FCH JU) Multi Annual Implementation Plan (MAIP) and Annual Implementation Plans (API) that it is difficult to formulate precise targets and requirements for stationary fuel cell applications due to the complicated interaction of FC system operation with grid specifics and the differing goals of FC implementation in the Member States. Neither for efficiency and emission levels, for example, nor for more technical specifications like cycling ability and turn-down ratio can clear targets be set and benchmarks applied that are independent from the energy supply grid[1] environment the FC system is operating in.

Therefore it was decided to omit such targets from the JU programme, which on the other hand constitutes an unsatisfactory situation due to the lack of clear technical guidelines in developing distributed generation fule cell units.

The project contributed to solving this situation by collecting and reviewing information on stationary FC operation in various grid environments and application strategies. From this analysis and using information on competing technologies and their future development, benchmarks and targets for stationary fuel cell applications in Europe were developed and coordinated with the FCH JU and industry stakeholders. These benchmarks will be helpful in shaping future JU programmes with respect to optimised allocation of research & development effort towards maximisation of primary energy savings and greenhouse gas emission reductions, as well as further environmental indicators.

Using a simulation model of several fuel cell, combustion engine and stirling engine residential combined heat and power (CHP) systems, results were obtained for heat and electricity following mode, and single and multi family houses located in different European countries (Poland, Italy, France, Germany and Finland). In a further exercise, a systematic sensitivity analysis was used to determine the break-even points for various system layouts, operating conditions and grid CO_2 footprints. In all cases, the viewpoint of an enduser was assumed, having the choice of installing a micro-CHP (µCHP) unit in his or her house or business.

The strongest statement that the project can make is that in favour of distributed CHP units with a high total efficiency. Coupled with a high electrical efficiency, this has a strong impact especially in grids with a medium to high CO_2 footprint. For grids with a footprint below about 200 gCO_2/kWh_{el}, the benefit of distributed generation and µCHP of whatever kind based on fossil fuels becomes debatable. However, the CO_2 benefits of the µCHP unit cannot be analysed merely based on the average footprint of the grid, since with growing numbers of units and future changes in the power generating technologies, marginal generation and displaced power generation will play a growing role. Therefore, a more encompassing energy system analysis has to be used in order to estimate the overall system benefits taking into account medium and long term energy and climate policy targets on the EU and country level.

[1] more generally what is sometimes called the „super-system“, including electrical grid, gas network, hydraulic circuit in the building, heating/electricity demand of the objects where the generating unit is installed, and other non –technical aspects such as economical context (linked to energy prices, feed-in tariff etc.)

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Introduction

Stationary fuel cells, other than mobile and vehicle applications that quasi ‘take their system environment with them’, operate under a variety of constraints which are defined by the energy supply grid they are integrated into and the application they serve. Generally, it will be said that stationary fuel cells offer the advantages of high efficiency operation with low emissions, low noise and modular design.

Nevertheless, a closer look at efficiency figures reveals that at the current status of technology practical efficiencies of fuel cell devices are often barely comparable with current power generating equipment. On the other hand, improvements in conventional generating plant are gradually rising to a level that some years ago was believed to be solely reserved to fuel cell systems. If we consider only emission balances and greenhouse gas (GHG) abatement, it must be acknowledged that the GHG savings from a fuel cell operated in the German grid will very much differ from those of a fuel cell producing electricity in France – simply due to the lower carbon footprint of the French electricity supply system.

An additional problem is introduced as different fuel cell types (PEFC, HT-PEFC, MCFC, SOFC) display different efficiencies in electricity production from natural gas, with the low temperature fuel cells generally operating at lower efficiencies due to the necessary gas processing whereas the high temperature fuel cells can utilise internal reforming of methane at considerably higher efficiencies. Still, the total efficiency of the low temperature variants may be higher due to the better use of exhaust heat and the latent heat in the water vapour produced.

As a result of this complex situation there is no simple means of predicting the advantages that a stationary fuel cell system would offer in any given energy supply environment. The task of setting minimum benchmark targets for projects to be awarded funding under the FCH JU scheme was therefore abandoned since there was no sensible way of setting general conditions that would apply independently to both technology and system integration across Europe.

The FC-EuroGrid project looked into the interdependencies of stationary fuel cell systems with electricity supply grids. The goal was to select and define benchmark indicators and measures that allow the assessment and comparison of fuel cells with conventional power generating technologies, but also amongst each other. Also, the project strove to identify optimal conditions under which fuel cells can offer a maximum of environmental and energy efficiency advantages.

The main objective of the project was to establish technical and economic targets and benchmarks that allow the assessment of fuel cells in stationary power generation. The fuel savings and CO_2 emission reductions are a function of the electricity grid structure and the fuels employed.

Using these results it was possible to determine, whether a fuel cell installation effectively improves fuel use and improves the CO_2 footprint, amongst other criteria.

From the point of view of the FCH JU, this insight can lead to a more focused allocation of research funding, identification of R&D gaps and objective comparison of fuel cell with competing technologies.

Methodology

Stationary fuel cells operate under a variety of constraints which are defined by the energy supply grid they are integrated into and the application they serve. Generally, stationary fuel cells offer the advantages of high efficiency operation with low emissions, low noise and modular design.

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The project will establish pertinent application categories (among them: µCHP, CHP, decentralised electricity production, etc.), establish benchmarks from the performance of competing power generating technology (in the different EU countries), identify the technical and economic targets for the key applications, and review the potential of the different fuel cell technologies to fulfil them. The goal is to collect all data necessary in evaluating the performance of stationary fuel cells in the European energy markets (predominately heat and electricity) and paving the way to objective criteria of best practice and minimum standards, as well as an appraisal of the type of applications that actually lead to reductions in gross energy consumption, emissions and depletion of fossil energy resources.

(1) The 'carbon footprint' denotes the figure of carbon dioxide emissions per kWh of electricity delivered to the end customer, as stated by electricity companies in their customer information. This is defined as the average specific GHG emissions of the utility's electricity production derived from annual statistics.

Results

The project used two main approaches to derive the results shown here:

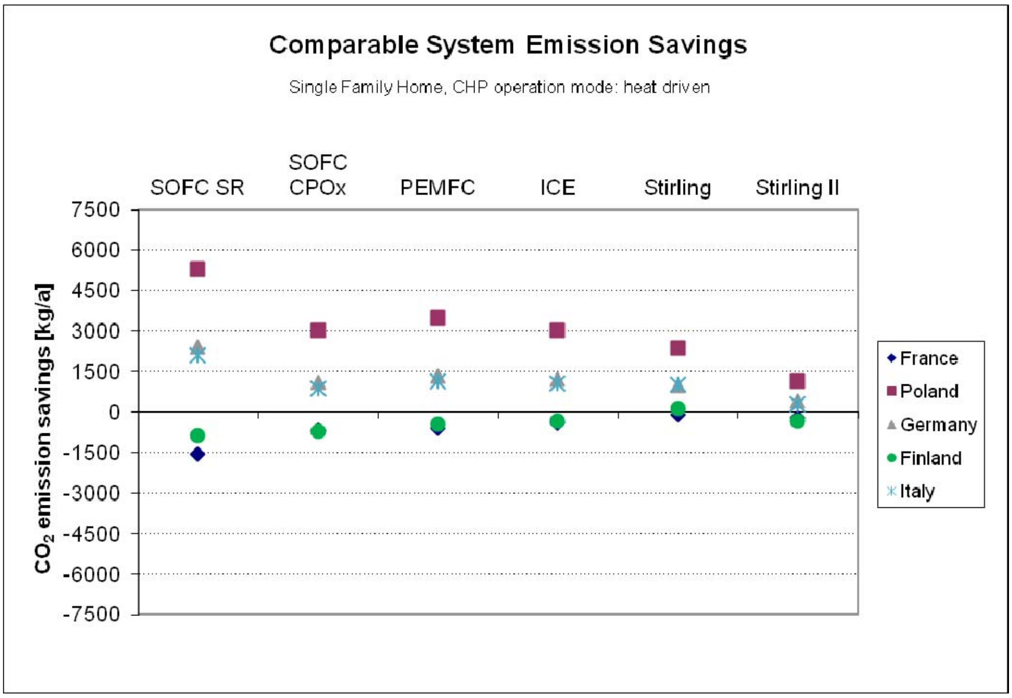
- model calculations with a simulation programme for residential electricity and heat supply in different European countries
- a sensitivity analysis of various parameters defining a micro CHP (µCHP) and distributed generation (DG) unit and its operating environment

The µCHP and DG units used and their main performance data are shwon in the following table:

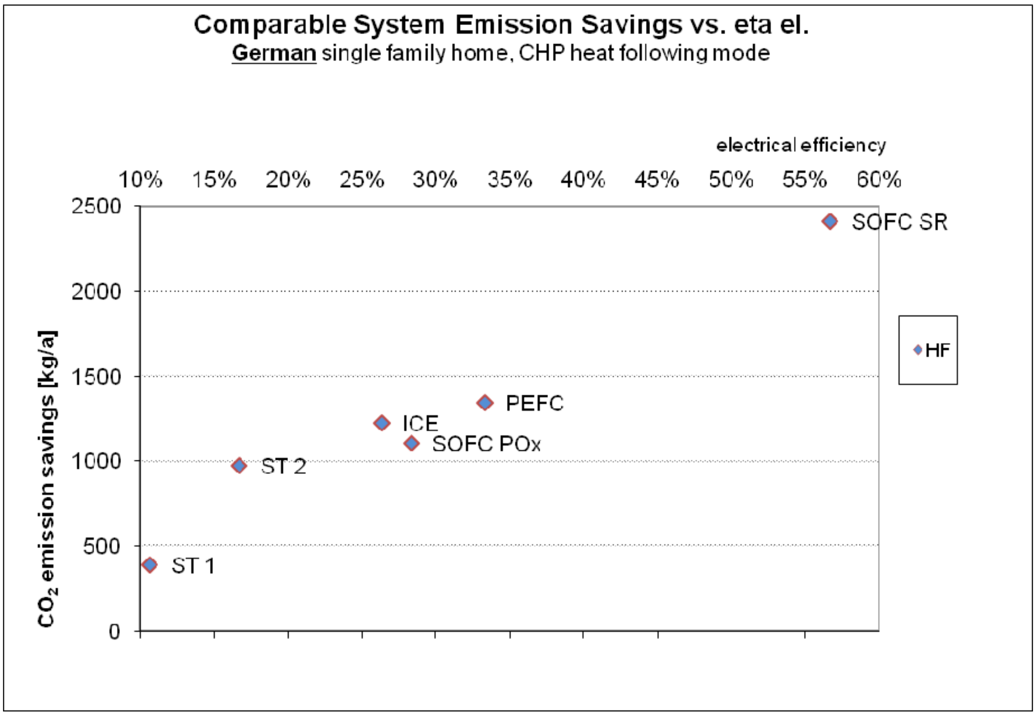
	Company	Name	Capacity		Efficiency el	Peak boiler	Total efficiency
			[kW$_{el}$]	[kW$_{th}$]	[%]	[kW$_{th}$]	
mCHP for residential applications							
Gas engine	SenerTec	**Dachs**	**5.5**	**12.5**	**27**		93
	ecoPOWER	**ecoPower 4.7**	**1.3 - 4.7**	**4 - 12.5**	**24**		96
	Vaillant/Honda	**ecoPower 1.0**	**1**	**2,8**	**22,5**	12 - 30	90
Stirling engine	EHE	**Wispergen**	**1**	**5.5 - 7.5**	**11**	14.5	**90**
	BDR	**eVita**	**0.9**	**7**	**13**	18	**105**
Fuel Cell	Baxi Innotec	**Gamma 1.0**	**0.3 - 1**	**0.5 - 1.7**	**32**	15	**85**
	Hexis	**Galileo N**	**1**	**2**	**30**	20	**90**
	CFCL	**Blue Gen**	**0 - 2**	**0.3 - 1**	**60 (at 1.5kW)**	20	**85**

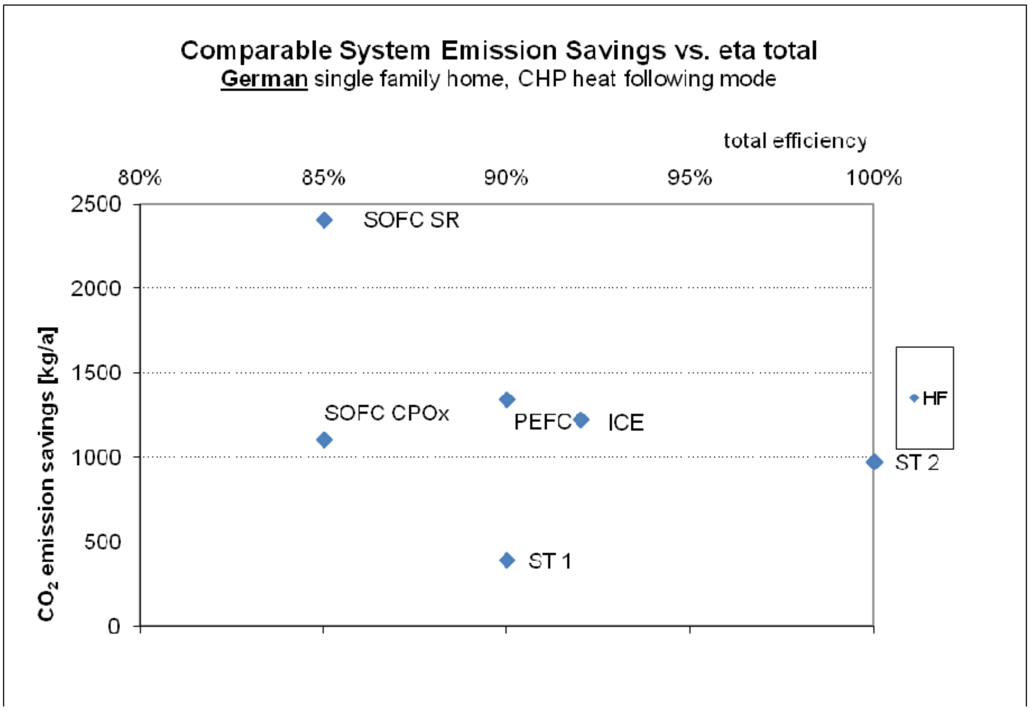
All the data are based on 'real' unit performance.

Fig. 1 shows the CO_2 savings for different µCHP and DG units running in heat following mode for different countries. Positive values indicate savings, negative values indicate additional emissions. It is obvious that the lower the carbon footprint of the exisiting electricity system is, the more negative the impact of the CHP unit.

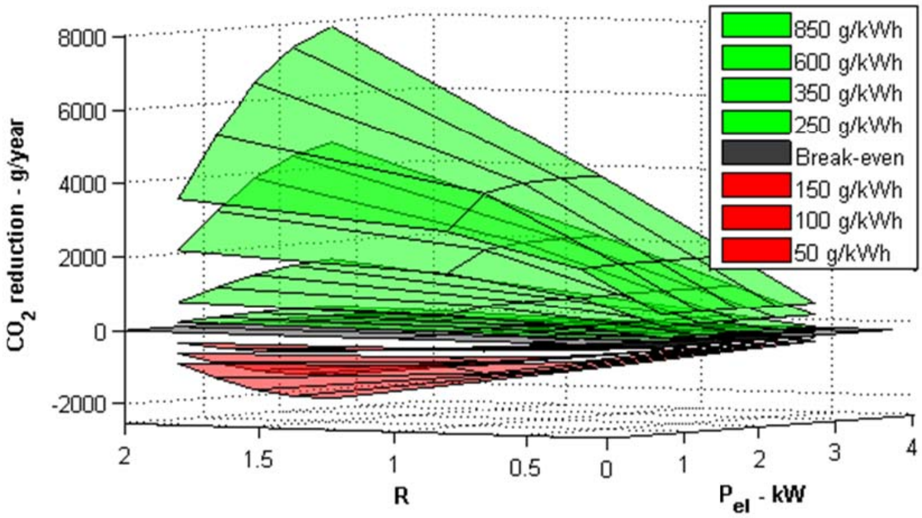


The results become more clear if the total efficiency and electrical efficiency are plotted as a parameter, in this case for the German single family home load curves, climate and current carbon footprint, as in Fig. 2 and 3 (HF: Heat Following mode):





The singular results of the simulation model were then further refined using sensitivity analysis. This method has the advantage that the tipping point between positive and negative impact can be immediately determined. Fig. 4 shows an example.



The R factor is the ratio of electrical to thermal power delivered, P_{el} is the electrical power and the z-axis gives the CO_2 reduction. Clearly, the higher the electrical efficiency (high R value), the higher the CO_2 savings in grids with sufficiently high carbon footprint. The break-even plane in this case is around 200 gCO_2/kWh, which is close to the emission factor of natural gas fuel. It is apparent that the electrical power rating only has a major impact at high electrical efficiency (high R value). This is based on increasing delivery to the grid substituting high carbon footprint electricity.

Outlook and Recommendations

From the results presented it is obvious that the CO_2 savings that can be achieved by a residential fuel cell installation in Europe will widely vary with location and the carbon footprint of the respective grid. It can be argued that the strong integration between most European grids will not allow a discrimination of the local carbon footprint on a purely physical basis, since the electric power flow in the grid will not be traceable to a specific source. Nevertheless, grid operators have to declare their emission balances throughout the EU and it can be assumed that it is correct to allocate this balance to the point of use of the respective customer.

Having said this, it is clearly a different case of employing a distributed generation (DG) unit in a grid with a high carbon footprint (e.g. Poland, Germany, UK, Italy etc.) or one with a relatively low footprint (e.g. France, Finland etc.). This statement is based on the methodology of limiting our view to the point of use, looking into the case of a customer choosing their energy supply equipment. The statement will change, if the electricity substitution is not referenced to the average kWh replaced but the marginal kWh, or when scenaria of whole market segments being equipped with µCHP and DG units are considered. In which cases the comparison would not be made with the average grid carbon footprint but with the carbon emissions of the power generation unit that would deliver the next incremental kWh or with the footprint of the generation band competing with the µCHP/DG produced electricity.

Assuming that the market introduction phase of fuel cell based µCHP/DG units will be dominated by end user choice of equipment at least for the next ten years, this approach has been adopted throughout this project. This view was agreed with the FCh JU.

Therefore the following conclusions can be drawn:

- the main benefits of µCHP/DG units based on fuel cells compared with conventional technologies will be a reduction of primary energy use in the combined generation of electricity and provision of space heating and warm water, a reduction in overall greenhouse gas emissions (except in those countires with high share of low-carbon electricity sources), and a reduction of grid losses,
- although the reduction of greenhouse gas emissions will vary with the carbon footprint, the savings in primary energy are in general very pronounce, since the efficiency of the power supply to end customers does not vary as much across Europe as does the carbon footprint (of course, if a large share of primary energy comes from renewable resources and/or nuclear, the savings will be of little value – in this case the competition or complementarity between µCHP/DG and renewables and other low carbon electricity requires a closer analysis),
- therefore total efficiency of µCHP/DG units is essential in providing environmental benefits; this figure determines the overall primary energy savings even in grids with low carbon footprint,
- likewise the electrical efficiency is of high importance especially in the future with higher penetration of low and passive energy buildings, and should be as high as possible, although this hardly imporves the CO_2 savings in grids with low carbon footprint,
- any other indicators (other emissions, indirect costs, etc.) will be directly coupled to the forementioned figures and show the same respective behaviour,
- in Northern Europe, heat following mode combined with a heat storage is the only operational mode that may lead to significant savings; trying to avoid feeding into the grid (by electricity load following) leads to sub-optimal performance with respect to emission reduction and primary energy savings; the case of coupling with cooling and air conditioning units was not inspected in this project,

- the investment cost reduction necessary in competing with today's cost of energy provision is high but not as dramatic as often claimed; the cost of a 1 kW µCHP unit, including 10 kW backup boiler, could lie in the order of 10.000 EUR.

The following recommendations may be drawn based on the project results:

- residential fuel cell µCHP units should be developed to high standards of total energy efficiency close to 100% (LHV),
- residential fuel cell µCHP units should be developed to high standards of electrical efficiency above 55% (LHV),
- target costs for fully installed units should lie in the order of magnitude of current commercially available µCHP/DG units and can be marginally higher as the electrical efficiency increases.

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