Learning points from demonstration of 1000 fuel cell based micro-CHP units - Summary of analyses from the ene.field project

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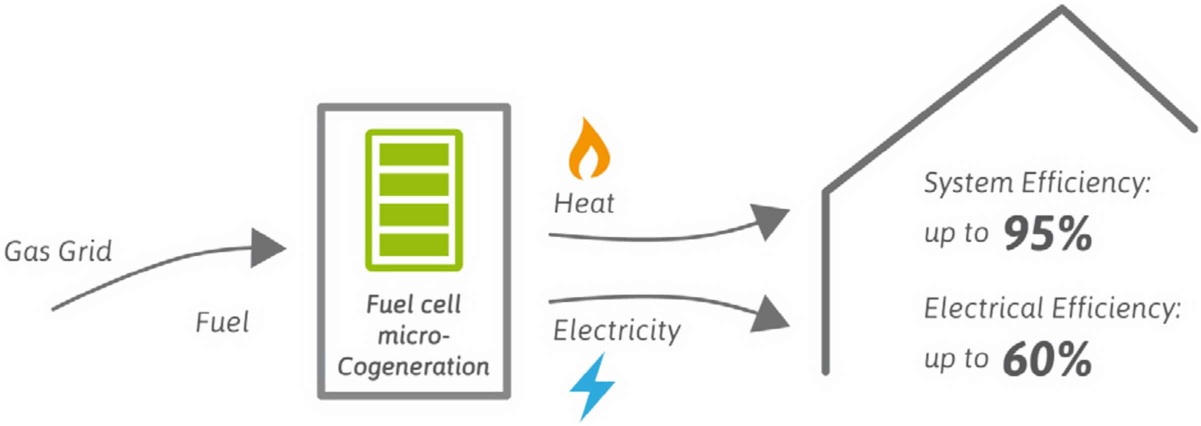
Summary of analyses from the ene.field project



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Technical University of Denmark
October 2017

This report and other ene.field public reports are available on http://enefield.eu/

Other background reports can be found on http://www.pace-energy.eu/

Learning points from demonstration of 1000 fuel cell based micro-CHP units

Summary of analyses from the ene.field project

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The ene.field project has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) for the Fuel Cells and Hydrogen Joint Technology Initiative (FCH-JU) under grant agreement N° 303462.

Executive summary

The ene.field project (*European-wide field trials for residential fuel cell micro-CHP*) has been Europe's (to date) largest demonstration project for FC micro-CHP (fuel cell based micro combined heat and power) systems. The project has demonstrated more than 1000 small stationary fuel cell systems for residential and commercial applications in 10 countries.

This report highlights learning points from the European demonstration project ene.field. It gives a brief introduction to the FC micro-CHP technology as well as the current status of the technology capability and potential, including barriers yet to overcome to reach a mass market.

Fuel cells can efficiently produce electricity and heat from natural gas. Large-scale roll-out of FC micro-CHP units can help the EU fulfil energy policy aims and climate commitments. An environmental life cycle assessment (LCA) of FC micro-CHP unit has been carried out as part of the project. This LCA concluded that **in general the greenhouse gas (GHG) emissions of a FC micro-CHP are lower than those of a gas condensing boiler or a heat pump** in all the investigated scenarios. Furthermore, the FC micro-CHP generally leads to **lower air pollutant emissions** compared with the alternative systems.

From a technical point of view, the FC micro-CHP is **ready for a large market penetration**. In the best 6-month period of the field trial, the **availability** of the units to the end-user has been **above 99%.** Of the total failures observed, only 1-2% were due to the fuel cell stack itself.

End-users participating in the ene.field project **were very positive** to the FC micro-CHP technology. In general, they were very satisfied with all aspects of their micro-CHP systems, especially the environmental profile of the technology. Based on the end-users' *perception*, the following two areas with some room for improvement have been identified: running costs and ease of use of the technology.

At today's **capital and maintenance costs**, FC micro-CHPs are **significantly more expensive than traditional heating technologies**. However, as serial production begins, economies of scale will cause the costs to drop substantially. The conducted life cycle cost analysis (LCC) showed that the FC micro-CHP **can become economically competitive with volume manufacture**. Increased sales encouraged by for example subsidies could therefore improve the near-term economics of micro-CHP units, and may be crucial for the technology to reach the mass market and hence for the EU to harvest the environmental and system benefits.

A number of aspects of the field trial turned out to be **more challenging than originally anticipated**. These aspects were routes to market, site selection, good business case for all involved partners, supply of components for the manufacturing, installation process and administrative procedures. These caused a delay in the deployment of units compared to the original plan. However, by the end of the project a **total number of 1046 units** have been installed which **exceeds the target of 1000 units**. The expected main route to market via utilities proved to be very difficult as less funding was available for demonstration projects than previously (e.g. for the German demonstration project Callux). The most successful approach for selling micro-CHP systems has been via installers through the heating market channels. A key element for a generally successful field trial is to **establish good communication channels with end-users and installers** beyond the basic technical discussion. The training of installers to ensure a smooth and faultless installation process is also key to successful deployment. During the project approximately **600 installers have been trained**.

Germany has been the most successful market for ene.field in terms of deployment numbers. More than 750 of the 1000 units have been installed in Germany. Funding from the national support schemes helps decrease the investment costs, and therefore favours the ramping up of the installation numbers. Moreover, high electricity prices make the technology more attractive in Germany than in other European countries.

The **installers** of FC micro-CHP units **find the systems easy to install**. However, the time required for completing the installation is longer than desirable. The installation times are likely to decrease significantly as installers become more experienced with the technology. In addition, further standardisation of components and training of installers are also expected to reduce the installation time.

Lack of a common framework for European standards is seen as a large hindrance to further market uptake. Countries use international and European standards, but supplement these with national versions. This mix of standards leads to problems for manufacturers who want to commercialise products throughout Europe. Furthermore, the forms for approval of installation lack standardisation and are partly complex and lengthy. A systematic and simple approach is required for the registration of new technologies.

The FC micro-CHP technology is **well suited for integration into smart grids**. A smart grid is a power grid where information and communication technology is used to manage generation, consumption and distribution of electricity, typically to compensate fluctuations in power generation from renewable energy sources (grid-balancing and peak-shaving). The micro-CHP units can be remotely controlled and can adjust to external heat and power demands at seconds' notice when at operating temperature. In order for micro-CHP units to contribute to grid stability, an estimated minimum of 1000 units need to be aggregated into a virtual power plant (1 MW).

The **German support programme KFW433** will facilitate the commercialisation of the FC micro-CHP technology in the coming years. As a follow-up on the ene.field project, field demonstration of FC micro-CHP systems in Europe continues with the **EU funded project PACE**.

About this report

The report gives an overview of the various analyses carried out as part of the ene.field project in the years 2012-2017 and presents learning points from the field trial. The topics reported can be read separately so that the readers may focus on their topics of interest. The Table of Contents will provide the necessary overview. Many background reports with further information exist. These are referred to in this report and most of them are available from the ene.field project website http://enefield.eu/category/news/reports/.

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This summary report has been written and compiled by DTU (Technical University of Denmark – Eva Ravn Nielsen and Carsten Brorson Prag) based on reports and input from all ene.field project partners.

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1 Introduction to FC micro-CHP technology

Fuel cells efficiently produce both electricity and heat from natural gas. This can be utilized in a combined heat and power (CHP) unit. Units with an electric capacity below 50 kW are usually referred to as micro-CHPs. Typical systems with capacity up to 5 kW are suitable for both residential use and small commercial buildings, see Figure 1.

FC micro-combined heat and power (FC micro-CHP) is a new technology that may replace the conventional gas boiler and provide homes with electricity as well as heat.

FC micro-CHP units allow for significant increases in the efficiency of heat and power production compared with traditional heating appliances and grid distributed electricity and, hence, they may bring a reduction in the overall primary energy consumption of the households. FC micro-CHP units allow for very efficient heat and power production compared to traditional heating appliances and grid electricity. The efficiency of energy conversion is above 90%, which is comparable with the energy conversion for the most efficient big scale CHP power plants. The FC on-site energy production ensures it is used without loss of energy in transmission, a loss that might be 5-10% for electricity and heat transport from big scale CHP plants. As the systems are installed at the end-use premises they can furthermore reduce the load on the electricity infrastructure and even provide a local peak capacity and assist in balancing the electricity grid.

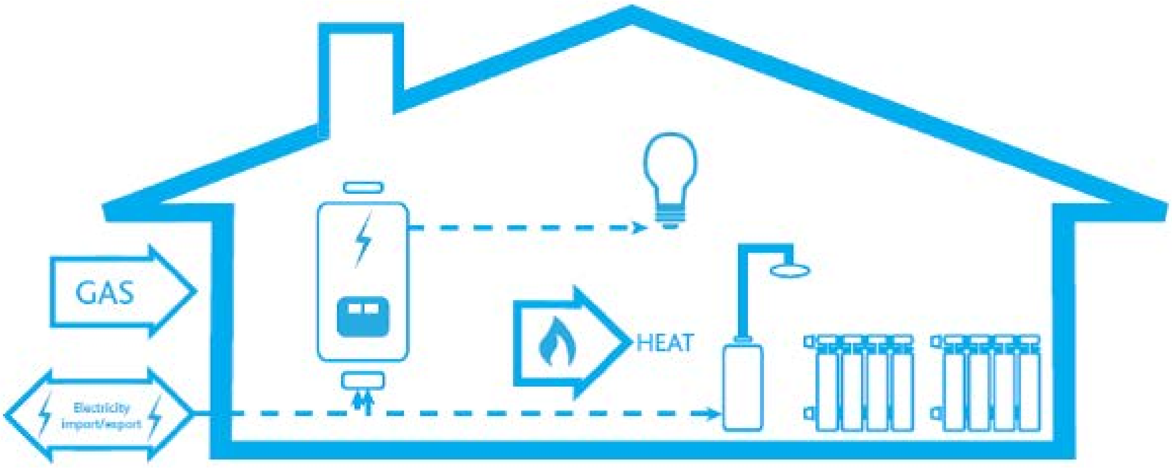


Figure 1. A fuel cell micro-CHP unit converts natural gas into heat and power.

Various types of fuel cells exist. For micro-CHP applications, two main types are used:

- Solid oxide fuel cells (SOFC), which operate at high temperatures (600-850°C) and are made from ceramic materials ("solid oxide")
- Polymer electrolyte membrane (PEM) fuel cells which operate at lower temperatures (60-160°C) and are based on polymer materials

Micro-CHP units are available in various sizes (electric capacity from 300 W – 5 kW) and have been optimised for various applications. They can operate in different modes: The systems may be designed to be heat-led which means that the operation is controlled by the heat demand of the building, or it may be electricity-led which usually means that it aims at a constant high electricity production.

FC micro-CHP units are complex systems including many components (see Figures 2 and 3). The systems can be designed in many ways for various purposes and can be more or less integrated. A typical FC micro-CHP system may include:

- Fuel cell module (see Figure 2), including:
  - Fuel processor (with reformer separated or integrated with the fuel cell stack)
  - Fuel cell stack (power section)
  - Inverter (power conditioner)
- Balance of plant components (may include heat exchanger, system control, gas recirculation system, valves, pumps, etc. in connection with the fuel cell module)
- Back-up boiler (gas condensing boiler for peak heat demand) and hot water storage tank
- Periphery (may include heating circuits incl. controls, heating circuits pumps, domestic hot water station, energy management system, domestic hot water circulation pumps, etc.)

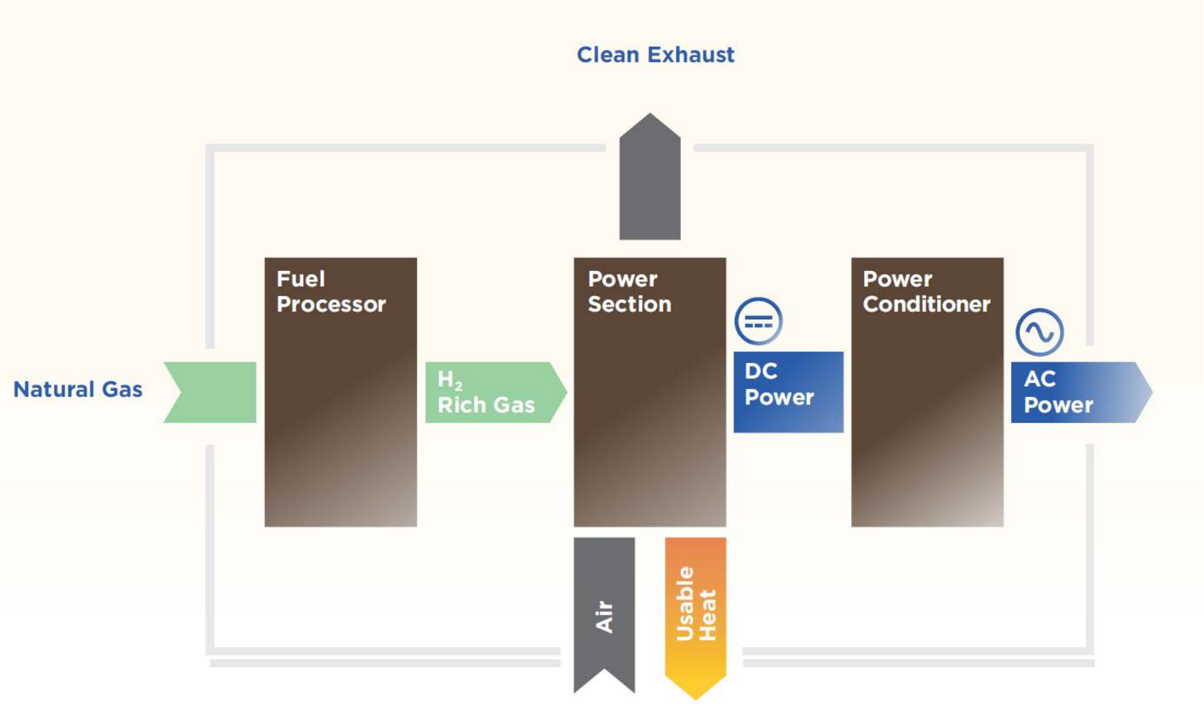


Figure 2. Sketch of the core components (the fuel cell module) of a typical FC micro-CHP unit. The input is natural gas and air; the output is heat, AC power and clean exhaust. The components are: 1) Fuel processor with reformer turning natural gas into hydrogen, 2) Fuel cell stack (power section) converting hydrogen into heat and DC power and, finally, 3) Inverter (power conditioner) converting DC into AC. The reformer and the FC stack may be separate or integrated. From [1].

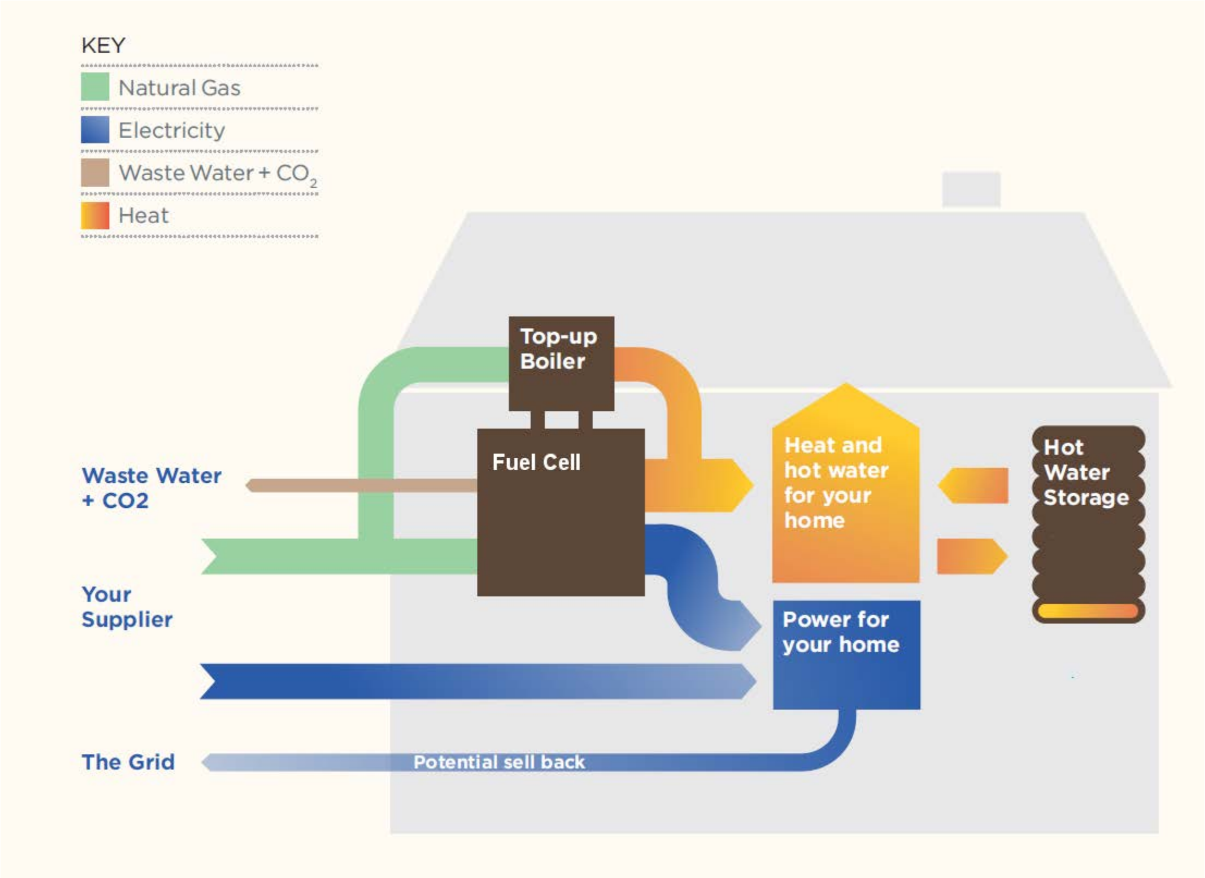


Figure 3. Simple sketch of a complete FC micro-CHP unit including gas condensing boiler for back-up (peak load) and hot water storage tank. After [1].

2 The ene.field project

The ene.field project has been Europe’s (to date) largest demonstration project for fuel cell based micro-CHP (micro combined heat and power) systems for private homes. The field trial brings real world learning of benefits and challenges of the technology.

The project has deployed more than 1000 micro-CHP units in 10 EU member states, see Figure 4. This is a step change in the volume of FC micro-CHP deployment in Europe and an important step to move the technology towards commercialization, see Figure 5.

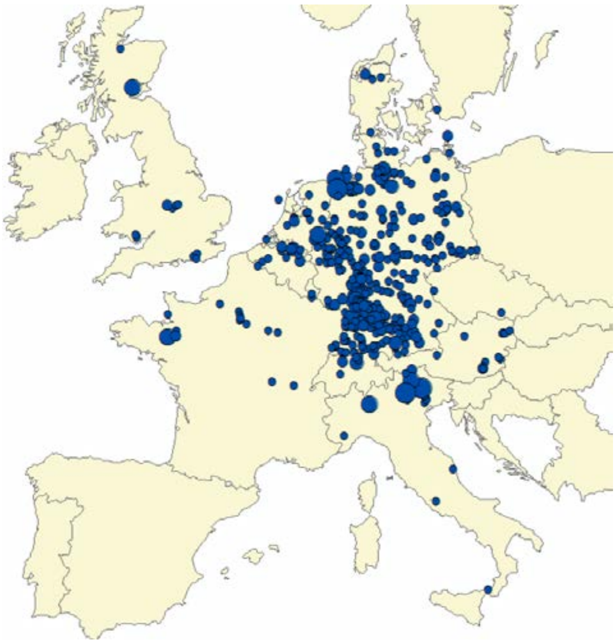


Figure 4. Locations of micro-CHP units demonstrated as of November 2016.

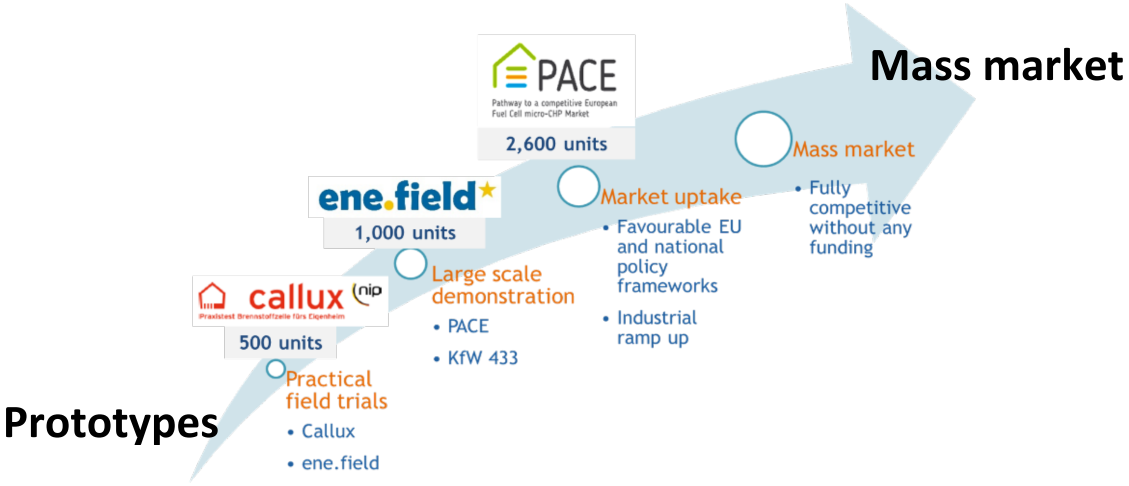


Figure 5. The ene.field project is an important step on the path from demonstration of prototypes to reaching a commercial mass market for FC micro-CHP.

The five-year project started in 2012. The main aim was to remove barriers to the roll-out of FC micro-CHP systems through large-scale deployment. Apart from deployment, the project focused on analyses of:

- Performance and barriers
- Environmental impact assessment
- Cost and market projections
- Policies and political challenges
- Requirements for standardisations

Most of the units have been equipped with meters to monitor the technical performance. Three surveys have been made involving end-users and installers. A number of complex analyses based on various data input and modelling have helped to evaluate the status and potential of the technology.

The project has involved 27 partners. Besides the manufacturers of fuel cell systems, several research institutes as well as utility companies have been involved as partners in the project. An overview of the project consortium is shown in Figure 6.

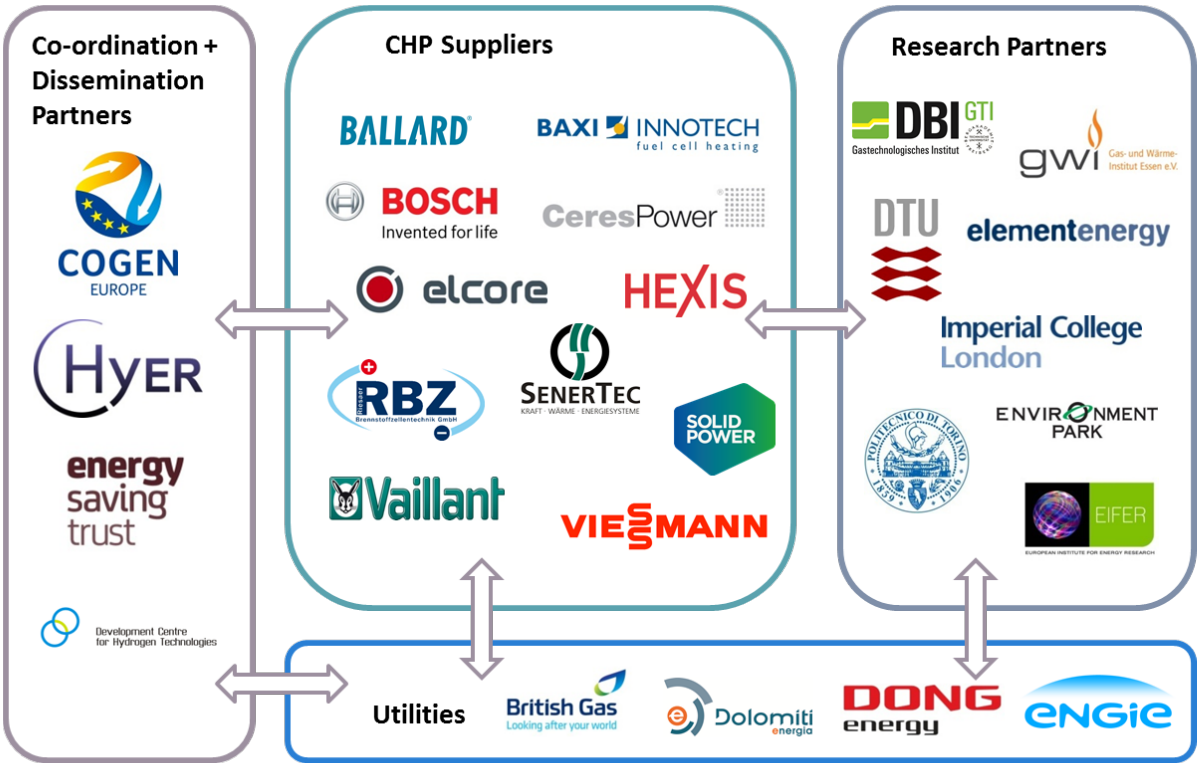


Figure 6. Overview of the ene.field project partners.

In the field trial, units have been demonstrated for 1-3 years. The first units were installed in 2013, but the majority of the units were installed in 2015 and 2016, see Figure 7.

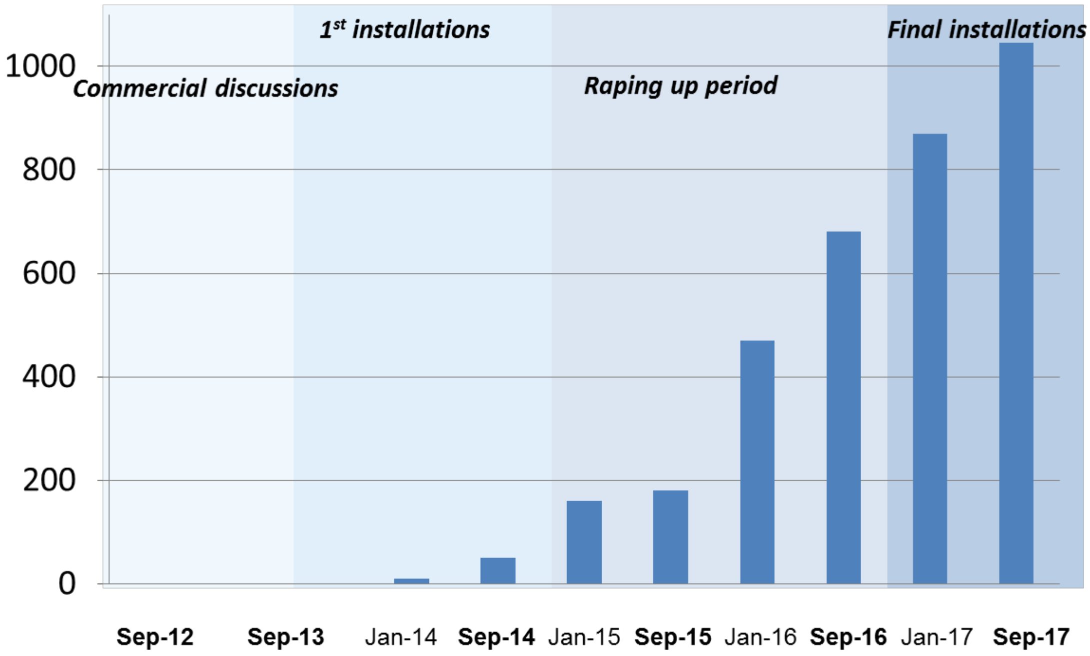
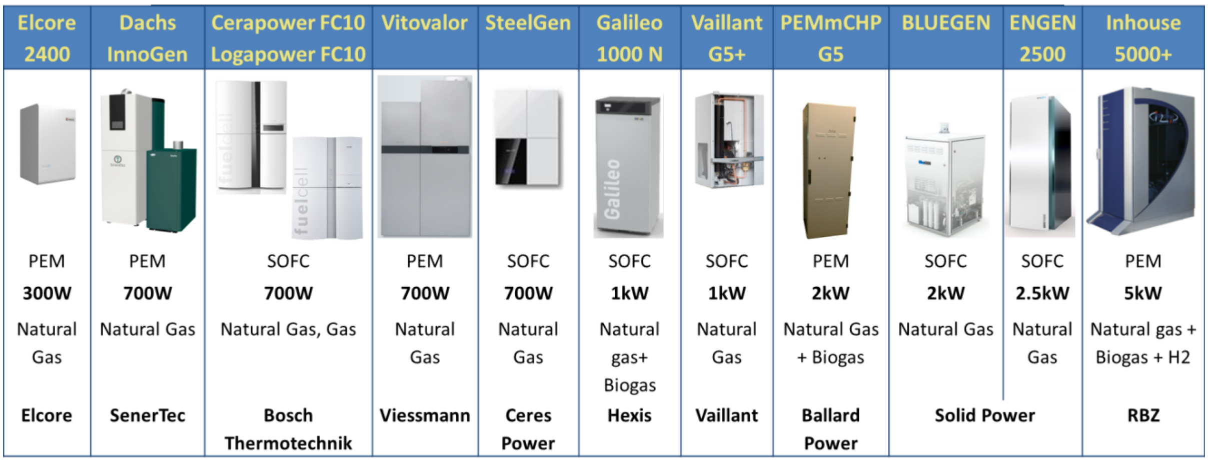


Figure 7. Installations over time during the project.

Units with very different characteristics have been deployed, see Figure 8 and Table 1. In total,

- 603 SOFC units and
- 443 PEM units

have been demonstrated with more than 5.5 million hours of operation in total and more than 4.5 million kWh electricity produced. The 1046 units installed have a total capacity of approximately 1155 kW of distributed power generation.



Elcore 2400	Dachs InnoGen	Cerapower FC10 Logapower FC10	Vitovalor	SteelGen	Galileo 1000 N	Vaillant G5+	PEMmCHP G5	BLUEGEN	ENGEN 2500	Inhouse 5000+
PEM	PEM	SOFC	PEM	SOFC	SOFC	SOFC	PEM	SOFC	SOFC	PEM
300W	**700W**	**700W**	**700W**	**700W**	**1kW**	**1kW**	**2kW**	**2kW**	**2.5kW**	**5kW**
Natural Gas	Natural Gas	Natural Gas, Gas	Natural Gas	Natural Gas	Natural gas+ Biogas	Natural Gas	Natural Gas + Biogas	Natural Gas	Natural Gas	Natural gas + Biogas + H2
Elcore	**SenerTec**	**Bosch Thermotechnik**	**Viessmann**	**Ceres Power**	**Hexis**	**Vaillant**	**Ballard Power**	**Solid Power**		**RBZ**

Figure 8. Characteristics of the various fuel cell micro-CHP units demonstrated in the field trial. The categories are name of model, type of fuel cell, electric capacity, possible fuel types, and manufacturing company.

Table 1. Summary of the characteristics of products demonstrated in the ene.field project. The thermal capacity includes the gas condensing boiler for backup/peak load. Efficiencies are under optimal conditions and have been calculated from the lower heating value (LHV) of the used natural gas.

FC Technology	PEM	SOFC
Electric capacity	0.3 – 5 kW	0.7 – 2.5 kW
Thermal capacity	1.4 – 22 kW	0.6 – 25 kW
System efficiency (LHV)	85 – 90 %	80 – 95 %
Electric efficiency	35 – 38%	35 – 60 %

2.1 General learning points from the field trial

Summing up the experience after the 5-year demonstration project with deployment of more than 1000 units has provided all partners with a long list of learning points and best practice for successful field trials. The key points have been listed below and have been further elaborated in Appendix A.

A number of aspects of the field trial turned out to be more challenging than originally anticipated. These aspects were routes to market, site selection, good business case for all involved partners, supply of components for the manufacturing, installation process and administrative procedures. These caused a delay in the deployment of units compared to the original plan. However, by the end of the project a total number of 1046 units have been installed which exceeds the target of 1000 units.

The experience gathered during the ene.field project has highlighted the need for early discussions with all stakeholders involved and the need to determining – before the installation occurs – the specific requirements of the site proposed for the system. This in turn allows for more rapid and smoother installation on site.

A key element for a generally successful field trial is to establish good communication channels with end-users and installers beyond the basic technical discussion. The training of installers to ensure a smooth and faultless installation process is also key to successful deployment. Until the technology is broadly understood by this group of stakeholders, it is still recommended that the manufacturers remain involved in the commissioning process.

A large amount of time and effort is required for the preparation of the information needed for the administrative preparation of each site (e.g. paperwork for grid operators, approvals, etc.). Forms have not been standardised, and in some cases a vast amount of documents have to be completed. The lead time for completing the paper works varies significantly between countries. In some countries, approvals may typically take 2-3 months. The administrative preparation for the site can be problematic for installers and end-users as these groups have no experience with dealing with this process.

A more harmonized approach to permissions and approvals is required for the market to progress. A standardised simple registration of new technologies producing decentralised electricity would be a good first step and, until this becomes a reality, it is still recommended that the manufacturers remain involved in the administrative preparation process.

2.2 Routes to market

The two main routes to market strategies of the manufacturers were:

- Contact with end-users established via installers, sales staffs, architects, etc. These stakeholders were mainly motivated by the prospect of increasing their product portfolio.
- Contact with end-users established via utilities or energy service companies (ESCOs). These stakeholders were mainly motivated by the prospect of potential business cases.

The most successful approach to selling the micro-CHP systems was via installers through the heating market channels. Sales under ene.field have been conducted via installers for as much as 80% of the total number of contracts signed by one manufacturer.

At the beginning of the project, it was anticipated that sales through utility companies would be the dominant route to the market (or route to the field trial installations), see Figure 9. However, the route to market via utilities has proved to be very difficult as less funding was available for demonstration projects than was the case for earlier projects (e.g. the German Callux project). During the ene.field project, utility companies have mainly been interested in demonstrating only a small number of units and have only contributed with limited co-financing of the units.

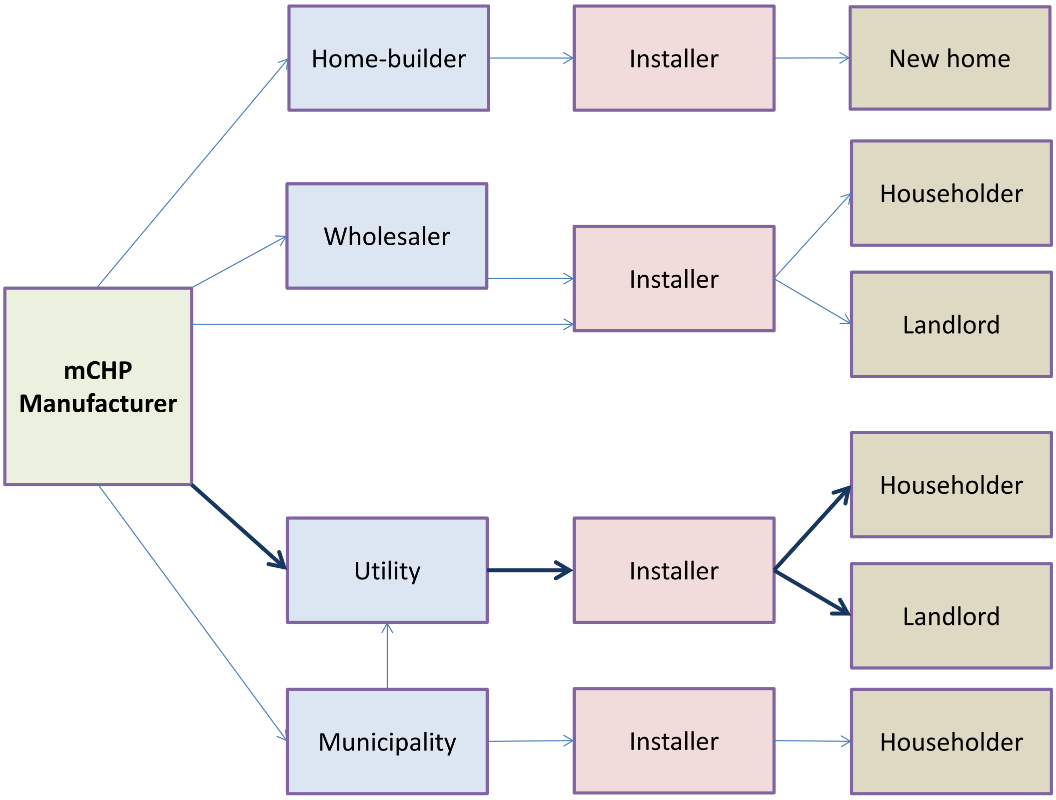


Figure 9 – The originally expected routes to market, including the expected dominant 'utility route'. Sales through utilities proved to be difficult and more sales were made directly to installers. *From the ene.field project description.*

Germany has proved to be the most successful market in terms of ene.field deployment numbers. The majority of the units deployed have been installed in Germany – more than 750 units, see Figure 10. This is mainly due to the presence of financial support schemes. Funding from the national support schemes helps decrease the investment costs and thereby favours the ramping up of the installation numbers. Furthermore, the German market is characterised by a better understanding of the technology by the end customers, installers and energy services suppliers as well as a favourable spark spread (difference between electricity price and gas price) which makes micro-CHP more beneficial. This trend is expected to continue as more units are installed as part of future deployment activities, with national or European support.

Section 5.4 of this report deals with the future routes to market.

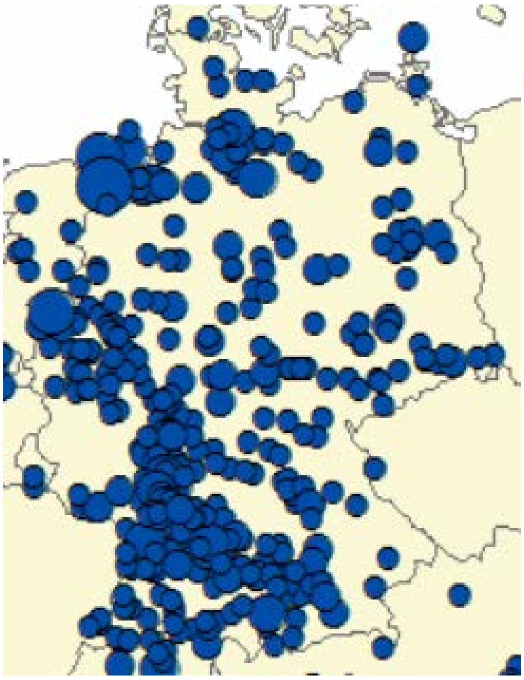


Figure 10. ene.field installations in Germany, November 2016.

3 Technical capabilities

The technical performance of all FC micro-CHP units in the field trial has been monitored. Performance data have been collected for 70% of the installed units in the ene.field project. Most of the units were subject to “standard monitoring”. Here, monthly data regarding gas consumption, calculated heat production, electricity production, operation hours and on/off cycles has been collected. 7% of the installed units were further equipped with sensors for “detailed monitoring”. In this case, data regarding e.g. electricity and heat production and consumption, electricity import and export, indoor and outdoor temperatures was collected every 15 minutes. Furthermore, all “issues encountered” (failures) were reported by manufacturers for all units in operation.

3.1 Efficiency

For the detailed monitoring, the fuel cell module (i.e. not including the backup gas condensing boiler) is equipped with a gas meter, power meter, heat meter and other sensors. All products have been tested in laboratories under controlled conditions. Efficiencies measured in the laboratory and in the field trial are shown in Table 2.

There are a range of uncertainties related to the field trial data. One example is the actual energy content (the lower heating value, LHV) of the natural gas used, as this varies across European locations. Nominal values have been collected for most sites.

To anonymise data for reasons of individual company confidentiality, the data from laboratory tests has been reported as average numbers for all the tested units. Unfortunately, this anonymization process limits the information which can be taken from the data, as an average number may cover data from both a 1 kW unit designed for optimal heat demand coverage and a 2.5 kW unit designed for constant operation and maximum electric efficiency. The averaged performance data from units does therefore not represent the performance of any of the individual tested units. This was the approach agreed by the ene.field consortium and used in the analysis of the performance data.

The efficiencies given in Table 2 are average numbers of all the systems tested even though the products are rather different in size, performance and optimal conditions. The laboratory testing includes 6 different SOFC products and 5 different PEM products. It should be noted that for the laboratory tests, the thermal and the electric efficiencies in the table cannot be added to calculate a total system efficiency as the two efficiencies may not have been realised under the same test conditions. Conclusions based on these data should be drawn with big reservation as each number represents a number of very different units as explained above.

The real-life data from the field trial has been taken from a period towards the end of the project where there was the highest number of units in operation. This gives the most robust data. The field trial includes very different types of units, ranging from early prototypes to commercially available products optimised for different applications. No conclusion can therefore be made regarding performance of individual unit types based on the average numbers presented here.

Table 2. Observed efficiencies of the fuel cell modules in laboratory testing and in the real-life field trial [2]. The data includes all the systems tested even though the products are rather different in size, performance and optimal conditions. The laboratory testing includes 6 different SOFC products and 5 different PEM products. No conclusion can be made regarding performance of individual unit types based on the average numbers presented.

For the real-life data, represent units in operation in the months September – December 2016. The st.dev. intervals represent the minimum and maximum values when calculating "average +/- one standard deviation" for each of the four months. The lower heating value (LHV) of the natural gas has been used for the efficiency calculations.

Note that for the laboratory tests, the thermal and the electric efficiencies cannot be added to calculate a total system efficiency, as the two efficiencies may not have been realised under the same test conditions.

	SOFC		**PEM**	
	Optimal conditions in laboratory test	Real-life data from the field trial	Optimal conditions in laboratory test	Real-life data from the field trial
Thermal efficiency, average	53%	46%	57%	57%
St.dev. interval		*30 – 59%*		*48 – 66%*
Electrical efficiency, average	42%	37%	32%	32%
St.dev. interval		*28 – 47%*		*28 – 39%*

3.2 Availability of installed units

Part of the monitoring of the FC micro-CHP units deployed in the ene.field project was an investigation of their availability to the end-users. The system availability was calculated based on information regarding system off time in connection with issues encountered. When an issue encounters causing the system not to be able to produce power or is not able to start-up in case of a heat demand, it is considered as unavailable. A service activity is also considered to be such an issue. The system is available, when it is not unavailable. The availability is the percentage of hours where the system is available. For the exact calculation, see the Technical Report & Report on Issues Encountered [2].

The average availability has been calculated based on units in operation in 6-month periods. For the period with the highest availability, both PEM units and SOFC units have availability of more than 99% [3].

These results show that the technology is well on its way to very high robustness. In previous projects, such as Callux and SOFT-PACT, availability between 90% and 96% has been reported. For the upcoming field trial in the PACE project, a goal of 99% availability has been set. The results from ene.field clearly show that this is feasible.

As part of the end-user perception survey (reported in section 6), a more detailed analysis of availability has been made of 67 units, see Table 3. Of these systems, 45% experienced no failures in the first year of operation and an availability of 100%. Hence, 55% had 1 or more failures. However, the vast majority of these failures were only for short periods of time; 90% of the FC micro-CHP systems were available for at least 95% of the time [3].

Table 3. Number of failures during the first year of operation and the corresponding availability. Based on units where end-users have participated in the surveys. After [3].

Number of failures	Part of systems	Availability (%)
0	45%	100.0
1	19%	98.2
2	24%	98.3
> 3	12%	86.9

3.3 Issues encountered – types of failure

Of the total failures encountered, only 1-2% of them relate to the core fuel cell stack component, see Figure 11. This result is in line with the robustness reported by stack manufacturers and shows that the core technology of the systems is reliable in real-life installations. 86% of the failures are not related to the fuel cell module and its core components (stack, reformer and inverter). However, the reformer and inverter are responsible for 12% of the issues encountered. An overview of the failures can be seen in Figure 11.

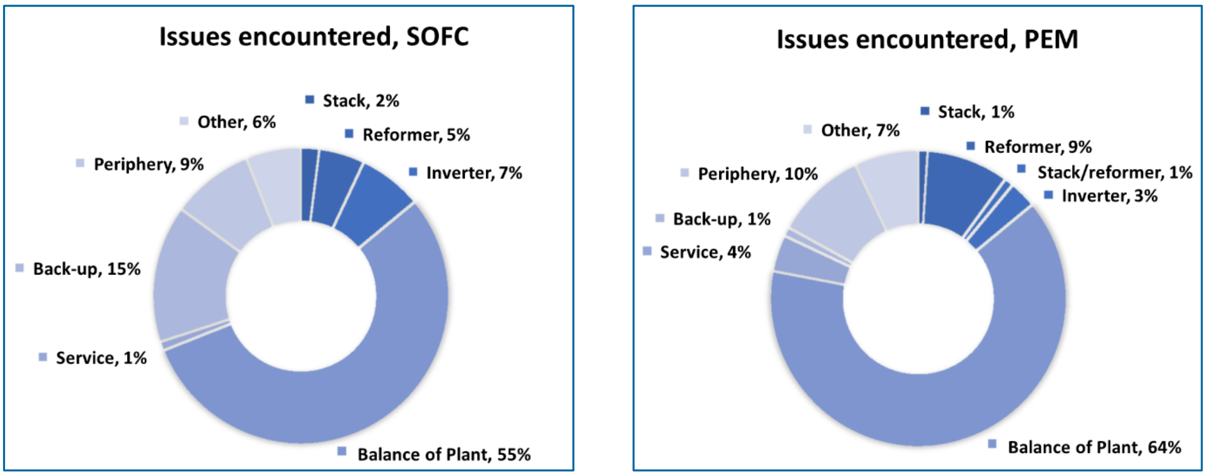


Figure 11. Distribution of the causes of failures for SOFC and PEM based micro-CHP in the field trial [2].

3.4 Smart grid capability

From a technical point of view, FC micro-CHP systems are well equipped for smart grid integration. Systems can typically be remotely operated and controlled. Furthermore, micro-CHP systems can adjust to external heat and power demands at seconds' notice when at operating temperature. Fast response times and aggregation capabilities make micro-CHPs well suited for smart grid controlled distributed generation which can limit transmission losses in the grid.

For micro-CHPs to positively contribute to grid stability in the context of the emerging smart grid model, the viability of aggregation of multiple units into a virtual power plant needs to be considered. At a capacity of 1 kW per system, an estimated minimum of 1000 units in a virtual power plant is required (1 MW). The rewards for the aggregator and installation owners will need to outweigh the administrative and coordination costs required for such a complex operation if the virtual power plant model is to gain ground.

The analysis of the smart grid capability is based on a survey among manufacturers and utility companies. See the full report [4] at the project website http://enefield.eu/category/news/reports/ for further information.

In the PACE project up to 250 micro-CHP units will be operated in a smart grid and controlled as virtual power plant. This demonstration will be detailed analysed to further prove the capabilities and potentials.

3.5 Installation process

An installer survey polled the installers about the perceived ease or difficulty of various aspects of the FC micro-CHP installation and the time taken to carry out the installation.

The installers reported that the systems were generally easy to install. Regarding the installation time, all installations took at least 2 days, with most installations taking 4-6 days.

As an installation requires multiple visits to the installation site by a handful of professionals before, during and after installation, these numbers are more reasonable than they may appear at first glance, especially when compared with a standard gas boiler that requires 2 days of installation. As a natural consequence of demonstrating new technology, many of the installations represent a first or an early installation for the installers. Therefore, the installation times are likely to decrease significantly as installers become more experienced with the FC micro-CHP installation process. Given that the shortest installation times in the project were 2 days it is reasonable to assume that this is a reasonable a target for normal installation by an experienced installer in the future.

For the future, further integration and standardisation of components and further training of installers may be ways of reducing the required installation time. The installer survey has been reported in [3].

3.6 Grid connection

Early in the ene.field project, an overview was made of requirements, guidelines and issues in relation to connection of FC micro-CHPs to the gas grid and the power grid. The report covers several European countries.

The installation procedure is similar in most countries, but with national supplements such as requirement for an additional electric breaker and for outdoor installation of the breaker so that the network operator has constant access.

The most frequently observed issue relates to the inverter which is sensitive to disturbances on the grid as well as to power outages. This often leads to a sudden stop of the micro-CHP as the inverter will trigger the safety system and thereby shut down the whole system. See the full report [5] for further information.

4 Environmental life cycle assessment (LCA)

The environmental performance of FC micro-CHP units has been assessed for various scenarios, varying notably in terms of a home's space heating demand depending on occupancy (i.e. single vs. multi-family homes), insulation level and climate zone. The fuel cell systems (including a backup gas condensing boiler) have been compared with other technologies, i.e. stand-alone gas condensing boilers and air-water heat pumps. In all scenarios, the home has a hot water storage and is connected to the electricity grid. All comparisons consider systems that provide the same *function*, i.e. they provide the same amount of heat and electricity for a given home. The considered scenarios include different replacement mixes, i.e. different levels of carbon intensity of the electricity that is replaced by the micro-CHP.

The main findings are:

- In general, life cycle greenhouse gas (GHG) emissions of the FC micro-CHP unit are lower than for the gas condensing boiler and the heat pump in all the investigated scenarios.
- FC micro-CHP units generally lead to lower air pollutant emissions compared with the alternative systems as the electricity produced by the fuel cell causes less emission than the replaced electricity from the grid (based on the power sources considered in this analysis).
- The micro-CHP efficiency and the full-load hours of operation throughout the year are the main characteristics that influence the final LCA results. The full-load hours vary depending on the micro-CHP capacity relative to the home's demand, on the operation pattern, such as periodic off-time due to regeneration of the fuel cell, and whether the unit is heat-led or electricity-led.
- The environmental gain of micro-CHP is more evident in multi-family home scenarios than in single family homes because of higher electricity production replaced in the grid (resulting from more full-load hours at a higher rated capacity).
- The emission savings by heat-led micro-CHPs (relative to gas condensing boilers) are governed by a) a low heat demand of the home and thus a low utilization of the backup boiler, and b) a high carbon intensity of the electricity production replaced.

Figure 12 shows the life cycle CO_2–equivalent emission savings of the micro-CHP compared to the gas condensing boiler (GCB) as a function of the annual full-load hours. (The "full-load hours" is a measure of how much the unit is utilized: A unit generates a certain amount of electricity per year; the unit does not necessarily always operate at its full load (full capacity); the "full-load hours" correspond to the number of hours that the unit should operate at full load in order to generate the same amount of electricity.) The results have been shown for 3 different replacement mixes, i.e. for three levels of carbon intensity of the electricity that is replaced by the micro-CHP.

Please consult Environmental life cycle assessment (D3.4) - Executive summary [7] at the ene.field project website for further details.

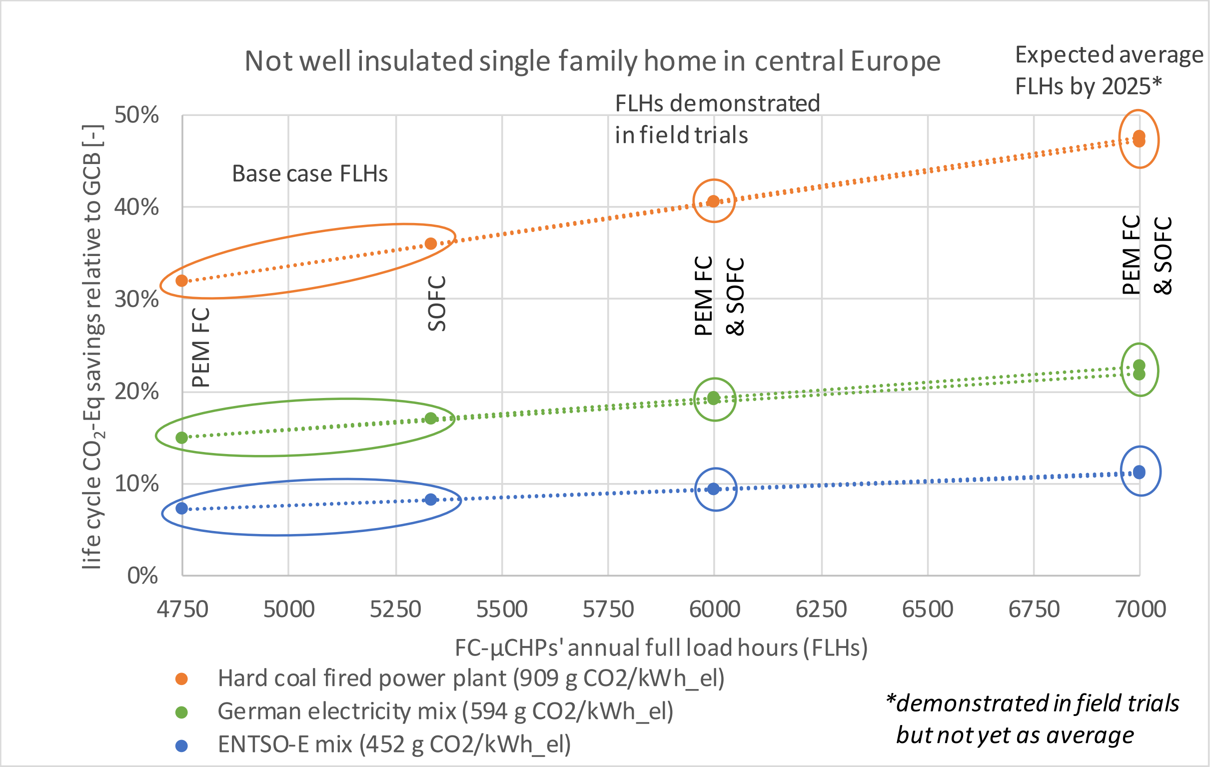


Figure 12. Life cycle CO_2-equivalent emission savings by fuel cell micro-CHP relative to a gas condensing boiler (GCB) as a function of the annual full-load hours (FLH) of the micro-CHP. Results are shown for different power production mixes that are replaced by fuel cell electricity. The scenario shown is existing (i.e. not renovated) single family homes located in central Europe, which is typical for the ene.field units demonstrated in field trials.

5 Economy

5.1 Life cycle cost analysis

At today's capital and maintenance costs, FC micro-CHPs are significantly costlier than traditional heating technologies. However, as serial production begins, economies of scale can be realised, and previous studies suggest that these costs are expected to drop significantly [8]. Over the last few years, deployment of micro-CHP units in Europe has gone from 10s of units to thousands, and several European manufacturers have made considerable steps towards commercialisation. In turn, this has led to updated estimates of costs and technical improvements that can be made as production scales increase.

A study of the Life Cycle Cost of FC micro-CHP was made based on the updated manufacturing costs and the performance projections [9]. It was compared with incumbent technologies. A number of key European markets were analysed, based on typical household heat demands as well as gas and electricity price data. The main conclusions are:

- Increase in production volume leading to reduced production costs (economies of scale) is crucial to the economics of micro-CHP.
- Micro-CHP units perform best economic wise in buildings with a high heat demand.
- At large-scale production, micro-CHP units can become economically competitive.
- Subsidies can improve the near-term economics of micro-CHP units, but can have the same effect on competing technologies.

The full report on the Life Cycle Cost Analysis [9] can be found at the project website.

5.2 Supply chain

An analysis of the EU FC micro-CHP supply chain has been carried out [10]. From a supply chain point of view, the main challenges for the FC micro-CHP technology are:

- Significant increase of production volume and reduction of systems costs, for example by outsourcing to suppliers
- Simplification of maintenance and part replacement procedures
- Development of maintenance networks of trained installers in more markets
- Reduction of system complexity and costs of components
- Development of collaborative strategies between key players

The study provides an evaluation of maturity, competition and standardisation levels of the micro-CHP industry in Europe as well as an analysis of the barriers and opportunities for the development of the supply chain. The full European Supply Chain Analysis Report [10] can be found on the project website.

In the on-going demonstration project PACE, activities are carried out concerning the supply chain. The following topics are being examined:

- Potential for supporting the European supply chain through joint action by manufacturers
- Learning from other sectors

The work is carried out with high attention not to violate any part of the European competition laws or antitrust laws.

5.3 Cost and market projections

An analysis of the future cost and market for FC micro-CHP systems has been made [11] and is summarized below.

A model has been created to simulate the potential for CHP uptake in Europe from 2015 to 2050. In order to guarantee a dependable model, the input data (i.e. the housing stock, the heating technology parameters, the cost down trajectory for product cost and the future energy landscapes) has been taken either from reliable sources (e.g. the Roland Berger report [8] or from the manufacturing companies), or it has been attempted to make realistic assumptions where no data was available.

The analysis considers three scenarios (from [8]) that differ in how widespread distributed generation solutions, where electricity is generated directly at the consumer, are. The characteristics of the three scenarios are shown in Table 4.

Table 4. Description of the scenarios for the future cost and market analysis. After [8].

Scenario	Degree of distributed generation	Policy support for distributed generation	Electricity price	Gas price	Carbon price (cost of CO_2 emissions)
“Untapped Potential”	Low	Low	Low	High	Low
“Patchy Progress”	Moderate	Existing, but fragmented	Low	Low	Moderate
“Distributed Systems”	High	High	High	Low	High

The analysis of the three scenarios shows the following:

- In the Untapped Potential scenario there is little commitment to distributed generation, and fossil fuels make up most of the energy mix. Distributed generation by FC CHP is expected to have a market share of only a few percent in 2050. Applying incentives (such as subsidies) can cause an early uptake, but this is not expected to make FC CHP a viable technology in the long run.
- The Patchy Progress scenario, in which the share of renewables has increased, describes a landscape for which, without incentives, FC CHP will only become competitive towards 2050. However, with capital cost support for FC or a high feed-in tariff, the uptake is dramatically enhanced, making FC CHP the dominant heating technology (of the options included in this assessment) from 2030 onwards.
- For the Distributed Systems scenario, no incentives are required to make FC CHP the dominant technology. However, the uptake is still enhanced by all incentive schemes. FC micro-CHP will become dominant as early as 2027 when incentivised by FC capital support or a high feed-in tariff.

Further interesting findings are:

- In some countries, the uptake of the FC CHP technology appears to be strongly enhanced by a renewable heat incentive even though this also incentivises the air source heat pump.
- For countries such as France that have low gas coverage only very little uptake of FC CHP is expected. This is a result of the assumption that significant costs will be incurred to establish gas connections to a large segment of the stock in countries that currently have limited gas grid coverage. Moreover, consumers are likely to be reluctant to the transition from electricity to gas due to “hassle factors”.
- In the United Kingdom, conditions appear to be poor for early uptake of FC CHP. However, when a 50% capital grant is applied (until 2021) in the Patchy Progress or Distributed Systems scenario, a strong uptake will start from 2021 onwards, reaching 60% establishment before 2040.

5.4 Potential routes to market

In parallel to the ene.field project, a study of business models and financing arrangements for the commercialisation of stationary applications of fuel cells has taken place [12]. This study was led by Delta Energy & Environment, and made on behalf of the Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) and will be widely cited in the following.

A wide range of business models have been analysed, see Figure 13. The study revealed that two fundamental types of business model would be the dominant options for introducing fuel cells to an increasingly large market:

- A ‘Product Sale and Service’ (offered with or without loan finance for the customer) where the end-user pays for the system up front. This is the predominant business model in use today for the sale of boilers in the European residential heating markets and has also been used for the majority of the stationary fuel cell sales made to date.
- An ‘Energy Services’ business model which enables the end-user to avoid the upfront payment by paying for it over time through his energy bills. The owner of the system will normally be an energy services company (ESCo) which offers the power and/or heat from the fuel cell unit as a service, or uses the unit as part of a contract to sell energy and heat to a consumer. This type of model is already used widely in the non-residential market.

The good news is that both of these business model types are in common use today throughout the energy services industry. Therefore, we do not believe there is a need for the industry to turn to a completely new type of business model to move fuel cells towards commercialisation. There is nonetheless room for innovation in the fuel cell business models.

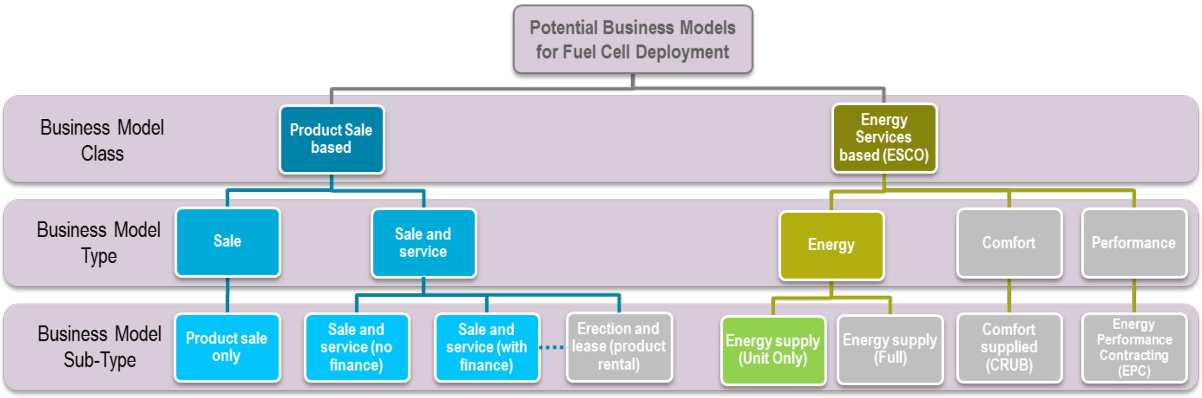


Figure 13. Recommended business models (coloured) [12].

Most residential FC micro-CHP systems are alternatives to conventional boilers for larger detached homes and multi-family homes where there is sufficient physical space for the unit. The study proposes a viable pathway through the application of several prioritised business models with the potential market segments. These include:

- The early stage customer segment “Affluent Green Pioneers” with the Sale & Service (unfinanced) business model. This segment is characterised by wealthy owners of large homes who have a strong environmental consciousness and a keen interest in new technology.
- The “*New Build segment”* with the Sale & Service (financed) business model. For this market, the higher cost of the fuel cell is ‘hidden’ in the price of the house and can be financed within a low-cost mortgage. This business model requires further research to confirm and demonstrate the suitability of fuel cells in the new build market via real world trials either through the existing technical demonstration programmes, or possibly a new FCH JU topic.
- Later stage segments/early mass market with both the Sale & Service (financed) and the ESCo business model. To enable penetration of the wider residential market, the higher capital cost of the fuel cell will remain a significant barrier to the uptake for the majority. This implies a new need to introduce loan finance either via easy-to-access lease finance for customers or through energy service (ESCo) offerings.

To date, the industry has been focussing its attentions on Germany, the European country where the fuel cell policy has been most supportive. Germany is the country with the greatest number of field tested units, where market creation efforts have been most intense, where electricity prices are among the highest in Europe, where the building stock is most suitable, and where customers are more accepting of residential fuel cell products and their high early costs. It will be necessary to identify other end-use segments both in Germany and other countries that can ensure deployment volumes will continue to increase.

For further details and recommendations on how FC micro-CHP may reach the mass market, see the final report of the study [12].

5.5 Macro-economic and macro-environmental impact

The overall macro-economic and macro-environmental impact of a widespread roll-out of FC micro-CHP technology to Europe's electricity systems has been analysed. In order to evaluate the system benefits of micro-CHP, a range of simulation studies has been carried out to examine the impact of micro-CHP on the European electricity systems (generation, main transmission, and distribution systems) for different future scenarios. The analysis considers today's grid mix and the impact of likely changes in the future.

The benefits of micro-CHP are quantified by finding the performance differences between two systems:

- A system without micro-CHP, called the **Reference scenario**, where the electricity was supplied by a portfolio of generation with no micro-CHP and the heat demand was met using electricity-heat pump
- A system with micro-CHP, called the **Micro-CHP scenario**, where the electricity demand was supplied by a portfolio of generation including micro-CHP which also supplied the heat demand.

It is important to note that the heat output of the micro-CHP only supplies part of the heat demand and therefore, other means of heating, e.g. gas boiler, heat pumps and resistive heating also exist.

The model is based on a whole-system approach able to capture all the energy system interactions of CHP, heat, electricity capacity and network services. The performance differences between the two systems, i.e. with and without micro-CHP determine the whole-system costs or benefits of micro-CHP on the system.

The values of micro-CHP in reducing the infrastructure cost (generation, transmission networks, heat pumps) and operating cost have been calculated in € per kW electrical capacity of micro-CHP for the years 2020-2050. The values reflect the cost saving of the system with micro-CHP in comparison to the cost of a system without micro-CHP. The CAPEX of micro-CHP is not included in the results; the OPEX of micro-CHP has been included.

The total (gross) benefits are from 6000-7300 €/kW in the differed years considered, with the 2040 case as an exception with values of 15000-16600 €/kW.

The results show that micro-CHP units can:

- Reduce operating costs. Net energy consumption is reduced indicating higher energy efficiency
- Release network capacity/postpone reinforcement at distribution and transmission networks
- Displace the capacity of central generators. The capacity value of micro-CHP units is comparable with a traditional gas-fired plant provided it can be dispatched as back-up
- Displace the capacity of alternative heat sources

The average benefits of micro-CHP on the European distribution networks are estimated to be 1600-2600 € per kW micro CHP installed.

Wide deployment of micro-CHP is not only improving the efficiency of the overall system but also reducing carbon emissions. The magnitude of the carbon saving per kW installed micro-CHP in Europe is estimated to be 370-1100 kg CO_2 per year. In the short and medium term, at least when the use of conventional coal/gas/oil-fired plant is still dominant, the impact of micro-CHP in reducing carbon emissions is expected to be relatively significant.

See the report Macro-economic and macro-environmental impact of widespread deployment of fuel cell mCHP [13] for further information.

6 End-user's perception

Two surveys have been conducted to collect information about end-user expectations and experience with the FC micro-CHP systems. The end-users participating in the ene.field project were very positive to the micro-CHP technology. In general, they were very satisfied with all the aspects of their micro-CHP systems. It is especially worth noting that their perception of the environmental profile of the technology was entirely positive. However, two areas with room for improvement were identified: running costs and ease of use of the technology.

End-users were asked how satisfied they were with their micro-CHP systems with respect to a number of criteria. The questions included satisfaction with:

- Comfort and warmth
- Heating and hot water production
- Electricity generation
- Overall satisfaction

The survey responses showed that the overall satisfaction was very good (an average score of 3.9 out of 5). Satisfaction with comfort and warmth, space heating, hot water production, and environmental performance scored higher than the average (4.3 out of 5), while the satisfaction with running costs and ease of use/controllability scored slightly lower than average (3.5 and 3.6, respectively).

The lowest scoring aspects of the systems are the most likely to be potential barriers to wider adoption of micro-CHP systems. Although running costs depend on wider political and economic factors and are not completely within the control of the manufacturers, improving the ease of use/controllability of the systems is something that is within the control of manufacturers. This could be down to improved system design, system documentation or after-sales support.

Based on the survey responses, 75% of the properties in which the units were installed were residential properties – and generally quite modern (post 1970s), large detached or semi-detached houses with gas heating systems. The end-users had relatively high household incomes. The remaining 25% were non-residential properties, including schools and office buildings.

The end-user surveys have been analysed and reported in more details in the Non-economic barriers report [3] to be found at the ene.field project website.

7 Policies and political challenges

A comprehensive review of the policy and political context that affects FC micro-CHP deployment has been made [15]. The study concluded that:

- Consumer and energy system benefits of micro-CHP systems are not adequately recognised and rewarded by policy at the EU and national levels.
- Administrative barriers for grid connection and accessing support schemes persist and, thus, hinder large-scale deployment of micro-CHP systems.
- A coherent, steady and predictable policy framework is the key for the European heating sector to invest in new products and develop new business models.
- Building codes and energy labelling should fully reflect the benefits for consumers and at energy system level which is not the case today. This will be an important driver for the micro-CHP technology to reach the mass market.
- Energy and climate policy should take a systems' approach, looking at the energy system as a whole and exploring decarbonisation and energy efficiency opportunities across the electricity, heat and gas networks alike.

At an EU level, there is a strong commitment towards decarbonisation of the energy sector. This commitment has been reinforced by the COP21 climate agreement. The means for this are mainly improving energy efficiency and increasing the share of renewable energy.

The European Commission has also prioritised energy efficiency actions and greening of the energy supply for heating and cooling in buildings, which can be seen from the recent publication of the "Clean Energy for All Europeans" legislative package and the "Heating and Cooling Strategy" [14]. The EU moreover focuses on research and innovation in the energy sector to ensure there is sufficient investment in new technologies at R&D stage.

Potential risks for FC micro-CHP deployment in the medium to long term, linked to EU level legislation, include:

- Focussing more on energy reduction at the end-user level instead of on energy system efficiency (final energy vs. primary energy reductions)
- Promoting electrification instead of other energy solutions for decarbonisation, and
- Supporting renewable energy across the whole energy system (electricity, gas, heat networks).
- Treating renewable energy as a substitute for energy efficiency

Large-scale deployment of FC micro-CHP systems will depend on the outcome of EU political negotiations on the "Clean Energy for All Europeans legislative Package" and the review of the "Energy Labelling and Eco-design" regulations for space heaters.

At the member state level, the policy support and the political commitment related to the FC micro-CHP technology varies. So far, Germany has made a strong commitment to the technology through the Callux field trial and the roll-out in 2016 of the major KFW433 programme. Other EU countries support the FC micro-CHP technology as part of their broader CHP policies. Yet, the majority of the member states do not support the market entry of FC micro-CHPs.

The complete ene.field policy recommendation report [15] can be found at the ene.field project website. Further information related to this topic can be found in the Non-Economic Barriers report [3] and in the Regulations, Codes and Standards reports [16-17].

8 Standardisation

An overview of the current regulations, codes and standards in Europe and at national level has been made in relation to the installation aspects of FC micro-CHP systems [16] and an additional report has been made based on experience from the field trials [17].

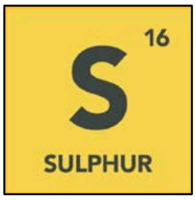
The main conclusions were:

- Countries use international and European standards, but supplement with national versions.
- A mix of standards leads to problems for manufacturers who want to commercialise the products throughout Europe.
- Energy labelling of FC micro-CHP systems was found to be unfair compared with other energy systems. The current methodologies used to calculate the seasonal space heating energy efficiency were found to poorly represent the performance of micro-CHP units, and this is what determines the energy label.

The lack of a common framework of European standards is seen as a large hindrance to market uptake. Manufacturers point to a need for updating, improvements or revisions of a large amount of the current standards. The issues include lack of consistency between different standards dealing with similar topics, and standards that refer to too general co-generation systems fitting poorly with the reality of the FC micro-CHP technology. The considerable amount of standards that in some way are relevant to FC micro-CHP installation makes it hard for the manufacturers to keep an overview.

The upcoming review in 2017-2018 at the EU level of the Energy Labelling & Ecodesign Regulations for Space Heaters represents an opportunity to amend the methodology for micro-CHP to fully account for the efficiency benefits of these technologies – which is not the case today.

9 Sulphur content in natural gas



The presence of sulphur and sulphur based components in natural gas may be harmful to fuel cells. For the design of suitable desulfurizers, it is crucial for the fuel cell manufacturers to have information about the sulphur content of the locally used natural gas, when they want to install FC micro-CHP devices across Europe.

A detailed mapping of natural gas odorisation practices in the European countries has been made, focusing on sulphur and sulphur based components. The mapping provides information on the type and amount of naturally occurring sulphur and sulphur containing odorants in the natural gas.

In general, the most critical aspect is the absence of a maximum concentration for the odorants injected into the natural gas in many countries. However, most of the countries have a total sulphur content limit. In addition, it is possible to obtain a range of most probable sulphur concentration.

The full report [6] can be downloaded from the ene.field project website.

10 Training and field support

Early in the ene.field project, an evaluation of the state of field support arrangements, training and certification was made [18]. Towards the end of the project, the initial work was followed up by a survey among manufacturers and utility companies to review lessons learnt and future needs [19].

During the ene.field project, the training of installers has progressed tremendously in active markets such as Germany. Approximately 600 installers have been trained in the course of the project. Some of the manufacturing companies have been training well above 100 installers each. However, the absence of organised training may be a barrier for market entry in new markets.

A good training process reduces the installation time and avoids installation related errors. The training should ensure a good understanding of both the fuel cell and the CHP technologies. The content of the courses should have a general common core with additional modules such as safety, regulation and standards, as well as micro-CHP operation and maintenance.

Training courses and training done internally by the manufacturers seemed to cover the present needs.

11 Future activities

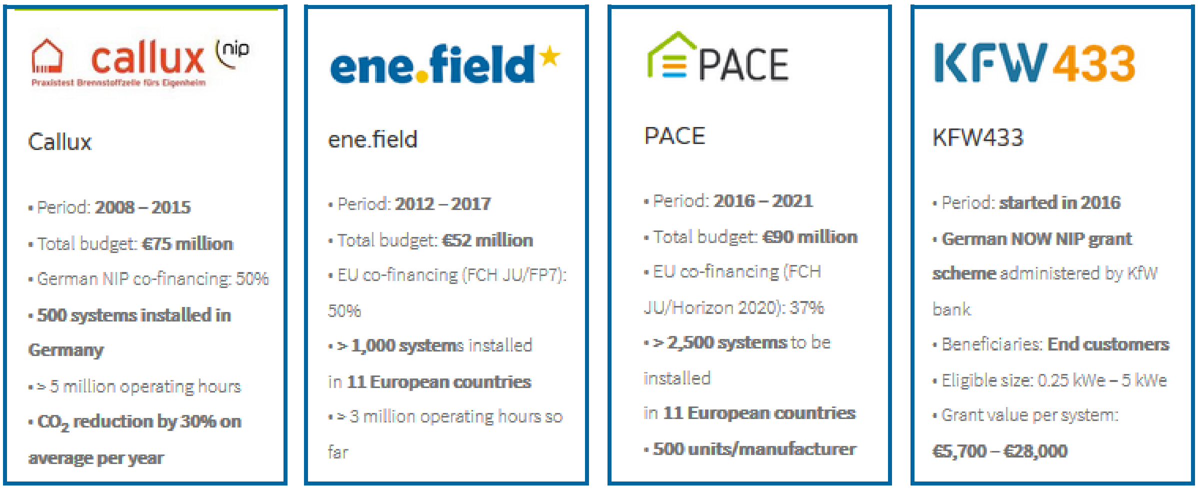
The PACE project is the natural next step following the ene.field project. *PACE* stands for “Pathway to a competitive European fuel cell micro-cogeneration market”. The aim is to install more than 2,500 FC micro-CHP units in 11 countries in the period 2016-2021. The focus areas are:

- Product innovation and cost reduction
- Supply chain development
- Policy collaboration
- Demonstration and verification of primary energy savings
- Testing grid benefits

Like the ene.field project, PACE is supported by the Fuel Cells and Hydrogen Joint Undertaking (FCH-JU). Further information can be found on the PACE project website www.pace-energy.eu

Furthermore, in the upcoming years the German programme KFW433 will enable large-scale deployment of FC micro-CHP units by subsidies.

Figure 14 shows the development in some major FC micro-CHP projects and support schemes.



Callux

- Period: **2008 – 2015**
- Total budget: **€75 million**
- German NIP co-financing: 50%
- **500 systems installed in Germany**
- > 5 million operating hours
- **CO_2 reduction by 30% on average per year**

ene.field

- Period: **2012 – 2017**
- Total budget: **€52 million**
- EU co-financing (FCH JU/FP7): 50%
- **> 1,000 systems** installed in **11 European countries**
- > 3 million operating hours so far

PACE

- Period: **2016 – 2021**
- Total budget: **€90 million**
- EU co-financing (FCH JU/Horizon 2020): 37%
- **> 2,500 systems** to be installed in **11 European countries**
- **500 units/manufacturer**

KFW433

- Period: **started in 2016**
- **German NOW NIP grant scheme** administered by KfW bank
- Beneficiaries: **End customers**
- Eligible size: 0.25 kWe – 5 kWe
- Grant value per system: **€5,700 – €28,000**

Figure 14. Overview of important FC micro-CHP projects and support schemes, past and present.

12 Conclusion

The ene.field project has demonstrated more than 1000 fuel cell based micro-CHP units in 10 countries. From a technical point of view, the FC micro-CHP technology is ready for large market penetration. In long periods of time, the availability of the units to the end-user has been above 99%. Of the failures encountered, only 1-2% of them were caused by the fuel cell stack itself.

A number of aspects of the field trial turned out to be more challenging than originally anticipated. These caused a delay in the deployment of units compared to the original plan. However, by the end of the project a total number of 1046 units have been installed which exceeds the target of 1000 units. The expected main route to market via utilities proved to be very difficult. The most successful approach for selling the micro-CHP systems was via installers through the heating market channels.

A key element for a successful field trial is to establish good communication channels with end-users and installers beyond the basic technical discussion. The training of installers to ensure a smooth and faultless installation process is also key to success.

Large-scale market uptake of FC micro-CHP systems may help the EU fulfil energy policy aims and climate commitments. In the investigated scenarios, the life cycle emissions of greenhouse gas (GHG) of a FC micro-CHP are in general lower than those of a gas condensing boiler or a heat pump. Generally, the use of micro-CHP units also leads to lower air pollutant emissions compared with the alternative systems.

At today’s capital and maintenance cost levels, FC micro-CHPs are significantly costlier than traditional heating technologies. As serial production begins, economies of scale will cause the costs to drop significantly. A life cycle cost analysis (LCC) has shown that the FC micro-CHP technology can become economically competitive. Subsidies can improve the near-term economics of micro-CHP systems, and may be crucial for the technology to reach the mass market.

Germany has proved to be the most successful market in Europe in terms of deployment numbers. Funding from the national support schemes helps decrease the investment costs and thereby favours the ramping up of the installation numbers.

A lack of a common framework of European standards is seen as a large hindrance to the market uptake. Countries use international and European standards but supplement with their own versions. Moreover, the forms for approval of installation lack standardisation and the process may be complex and lengthy.

The end-user participating in the ene.field project were very positive to the micro-CHP technology. In general, they were very satisfied with all aspects of their micro-CHP systems, especially the environmental profile of the technology.

The German support programme KFW433 will facilitate the commercialisation of the FC micro-CHP technology in the coming years. As a follow-up on the ene.field project, the field demonstration of FC micro-CHP systems in Europe continues with the EU funded project PACE.

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Appendix A. Learning points from the field trial

Business cases and sales

- The most successful approach to selling the micro-CHP systems was via installers through the heating market channels.
- The impact of regional and governmental support was a key factor of success. This support can take a variety of shapes.
- The key hurdle for sales remains the price of the system when compared with the cheapest available technology in the market (i.e. the gas condensing boiler). The reason for the remaining high price even after subsidies is the remaining high costs of the technology and the high efforts required for the installation process, for the installation itself and for training and planning the installation. While this is expected to decrease in the coming years as production volume increases and allows economy of scale, this will continue to determine the sales strategies for the coming years.
- Customers expect extensive information on economic and environmental benefits of the system – sales teams and installers should be equipped with adequate material, and the consultation and site selection process should include a review of the customers' expectations and the expected outcomes following the installation.

Site selection and preparation

- Reviewing and confirming the suitability of the site (onsite inspection with the customer, plumber, electrician and manufacturer's teams) is the key to a smooth installation process. The sites selection should include a detailed review of the customer's profile and adequacy should be verified against a checklist following the first expression of interest from the customers.
- The paperwork before and after the installation can be problematic for installers and building owners as they do not have any experience in dealing with this process and as the requirements can be complicated. Some support should be offered for completion of the required paperwork.

Maintenance

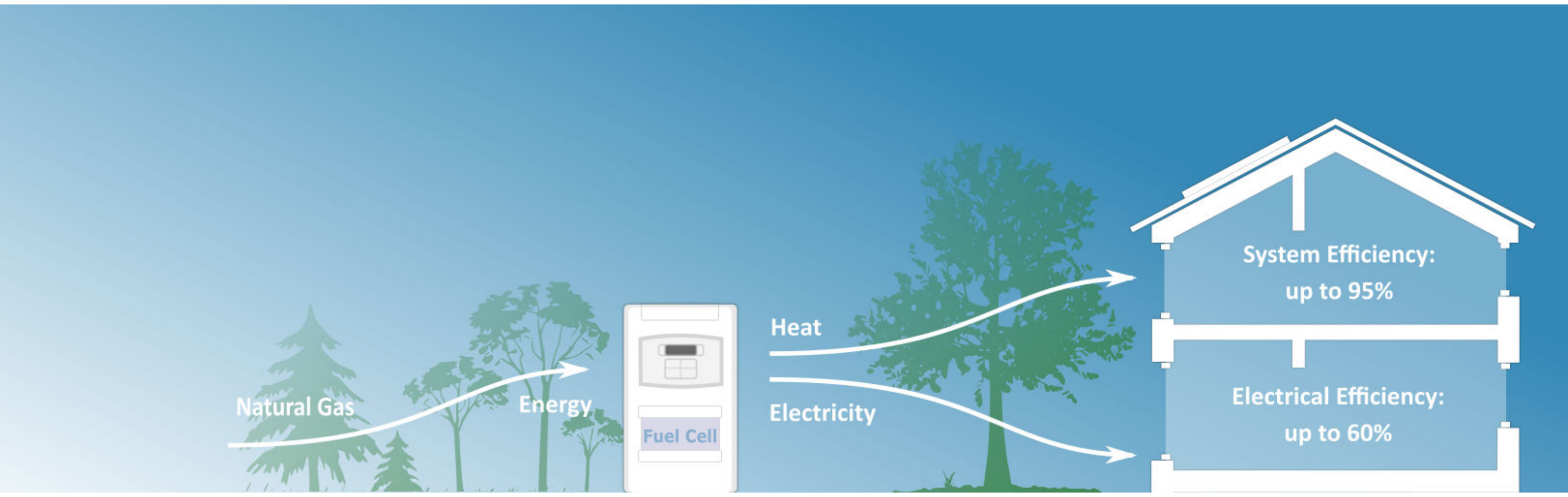
- The systems should be designed to ease maintenance.
- It is recommended that to have a document listing the error codes together with a short description of what to do and advice regarding the needed spare parts for each error code, and this document should be available to the service centres.
- To allow for shorter response time, the establishment of a network of local service technicians is necessary. They should be trained to handle first and second level repairs.

Training

- As of today, training of installers is done by the manufacturing companies themselves. For a larger deployment, this training would need to be formalised in an accredited training course to supplement baseline gas-installer qualifications.
- Start the training as early as possible, but the time between the training and the first on site visit should not be too extended. Follow-up training/refreshment classes may be required.
- It is difficult for external installers to justify efforts and resources required for training and it is recommended to introduce incentives to make this group attend training.
- The first installation by an external installer should be done as part of a "guided commissioning" with support from the manufacturer.
- Additional focus during training on the following areas would be beneficial: (a) Training on marketing best practices to support installers in realising sales and (b) Tips for installation based on typical hurdles.

Customer feedback

- The customers have generally been very satisfied with the units that proved to be reliable and efficient.
- The customers expect extensive information on economic and environmental benefits of the system – sales teams and installers should be equipped with adequate material, and consultation/site selection should include a review of the customers' expectations and the expected outcomes following the installation.
- The characteristics of the FC micro-CHP systems and their operation were not always well understood by the end-users. It was found positive overall to discuss this with end-users. Giving feedback to the end-users relating to their systems' energy performances during the operational phase is also recommended.
- A number of country-specific requirements have been noted and have impact on the business case (willingness to pay, installation site, etc.).
- It is recommended to provide some level of support to the customers for completing the required paperwork.
- In general, further involvement of the end-users could be beneficial. For example, via display with operation data to help the customer to optimize self-use of electrical energy as it tends to be more advantageous to use the energy produced rather than feed it into the grid, especially where the feed-in tariff is lower than the electricity price.
- Some manufacturers have trained end-users in simple resetting tasks.


Natural Gas
Energy
Fuel Cell
Heat
Electricity
System Efficiency:
up to 95%
Electrical Efficiency:
up to 60%