Fuel cell cogeneration for building sector: European status

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The advantages of fuel cell based micro-cogeneration systems are the high electrical and total efficiency coupled with zero pollutants emission, which makes them good candidates for distributed generation in the building sector. The status of installations, worldwide and European initiatives and the available supporting schemes in Europe are presented.

Keywords: cogeneration; fuel cell; micro-CHP; building sector; demonstration project; supporting schemes

General context

Cogeneration is defined as the simultaneous generation of thermal and electrical energy in one process. The technological implementations of this concept are known as combined heat and power (CHP) systems. Cogeneration can be applied to different scales, from large centralized plants to buildings. Decentralized cogeneration systems installed in buildings are gaining an increasing interest and reaching wide diffusion, aiming to produce electricity and heat near end-users, meeting the demand for heating, hot water, while providing electricity to replace or supplement the grid supply. This concept is called "micro-cogeneration" (micro-CHP), defined as the local combined production of heat and electricity with an electric output lower than 50 kWel according to Directive 2004/8/EC. Micro-CHP can be applied to different kinds of end-users, from private dwellings to public and commercial buildings. In the residential sector, electrical capacities are typically up to 5 kWel and heat capacities up to 20 kWth, while in public and SME buildings, the ranges are 5–50 kWel electrical and up to 250 kWth thermal [1].

Three are the main micro-CHP technology types currently available: internal combustion engines (ICEs), external combustion cycles – Stirling engines, Organic Rankine Cycles (ORC) – and fuel cells (PEMFC and SOFCs). The large majority of commercial micro-CHP units currently installed are based on ICEs, Stirling engines and ORCs. The ratio between electrical and thermal generation varies between technologies, with lower ratios for combustion devices, thus better suited to large buildings with high heating loads, while fuel cell systems can reach electrical efficiencies up to 60% [2], being thus fit for self-consumption schemes of auto-generated electricity.

Micro-CHP systems are in the early phase of commercialization. In 2015, worldwide micro-CHP sales accounted to 270 000 units, with 15% of units installed in Europe and the remaining part mostly in Japan [3].

The main advantage of micro-CHP is that allows achieving a larger primary energy efficiency – above 80% [4] – compared to the separate production of heat and electricity, thanks to the recovery of waste heat from the process. The reduction in primary energy use due to higher efficiency results in the reduction of greenhouse gas (GHG) emissions, even if CHPs are not a zero-emission solution, because the vast majority are fuelled by natural gas. The increase in energy efficiency also results in lower operating costs for the users. On the user side, another advantage relies in the capability of micro-CHP systems to help transform consumers into energy 'prosumers' (i.e. producers and consumers), putting them at the core of future energy systems. From the point of view of the global European energy system, micro-CHP can also provide all the advantages of distributed electricity generation: help the grid stability by generating electricity close to consumption at times of need and improve the security of electricity supply. On top of that, micro-CHP diffusion has an economic impact, creating and safeguarding jobs [3].

Besides the aforementioned benefits, there are still some drawbacks or barriers hindering the wide adoption of micro-CHP units in the building sector. The most important are: the high first-capital cost, the lack or limited financial support to ensure a suitable payback period and sometimes administrative hurdles, such as authorization to electric grid connection. On top of that, local micro-CHP generation based on combustion technologies brings about environmental concerns regarding local emissions (such as NOx, CO, SOx, particulate matter, unburned hydrocarbons, etc.) [4]. The last drawback is overcome by the fuel cell micro-generation, which has near-zero local emission of pollutants because the core technology is not based on the combustion of fuels.

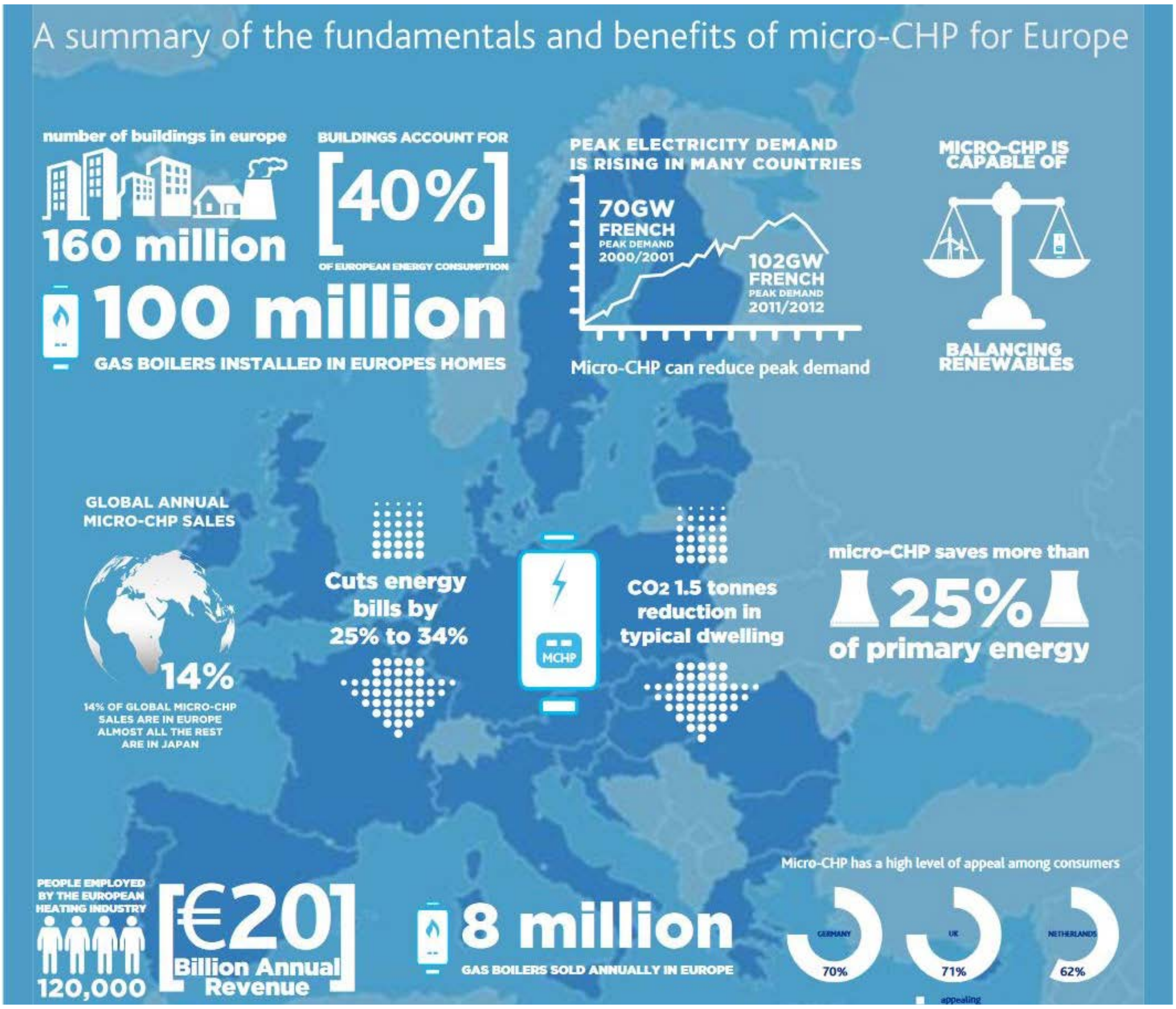

Figure 1. Benefits of micro-cogeneration in the building sector [3].

Fuel cell systems for the residential building sector

Fuel cell based micro-CHP systems could be a good candidate for the residential sector. Almost all the FC-based micro-CHP installations worldwide are considering FC systems of 0.5–1.5 kWel since most of the units are operated at constant point without modulation (electrical power production is sized to cover a "base load", while peaks are supplied by the grid). The authors have studied in previous works [5–7] the performance of high temperature SOFC and low temperature PEMFC cogeneration systems under different regulating strategies, configurations (heat pump, battery, etc.) and economic scenarios.

The first important launch of fuel cell based micro-CHP systems for residential use took place in Japan with the Ene.Farm project. As of December 31st, 2018, a total of 292 654 commercial Ene.Farm units has been deployed in Japan. The Japanese government supported for a long period the Ene.Farm program, with high initial subsidies, then gradually reduced as the industry matures and costs come down until subsidy will be unnecessary. **Figure 2** shows the trend of number of installations and costs from 2009 to 2017 in Japan. Investment cost for a FC-CHP system decreased from 24 900 € to 9 400 € (costs are referred to a typical size of 0.7–1 kW).

Europe has followed the Japanese initiative by financing fuel cell based micro-CHP installations in the framework of two projects, called Ene.field and PACE, financed by the private-public platform Fuel Cell and Hydrogen Joint Undertaking. Furthermore, a dedicated national program in Germany (KfW433) has helped the widespread use of the technology. According to the last available data from 2019, about 10 000 fuel cell micro-CHP systems have been deployed in Europe [8].

The Ene.field project (European-wide field trials for residential fuel cell micro-CHP, 2011–2017) has demonstrated more than 1 000 small stationary fuel cell systems (1046 units: 603 SOFC and 443 PEMFC) for residential and commercial applications in 10 countries, installing a total capacity of approximately 1 155 kW of distributed power generation. Among the installed units, more than 5.5 million hours of operation have been reached in total, with more than 4.5 million kWh electricity produced. **Figure 3** shows a map of the Ene.field project installations across Europe.

Germany has been the most successful market for Ene.field in terms of deployment numbers, with more than 750 units installed here. Funding from the national

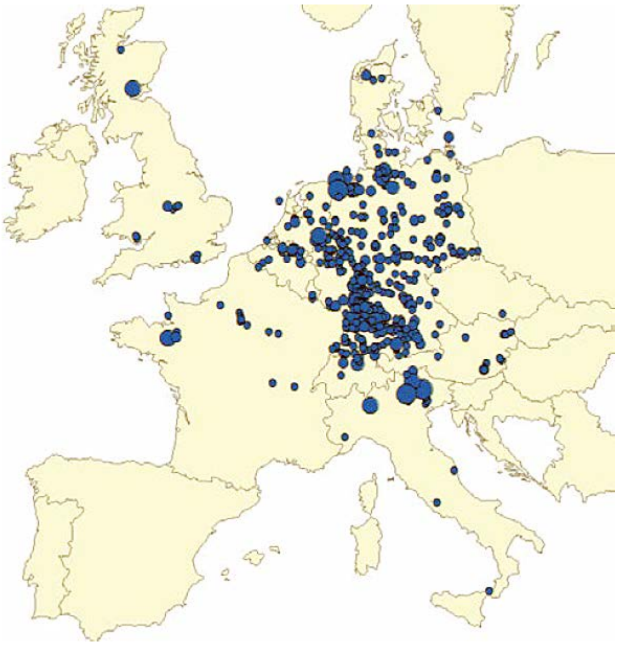

Figure 3. Locations of micro-CHP units demonstrated in the Ene.Field project.

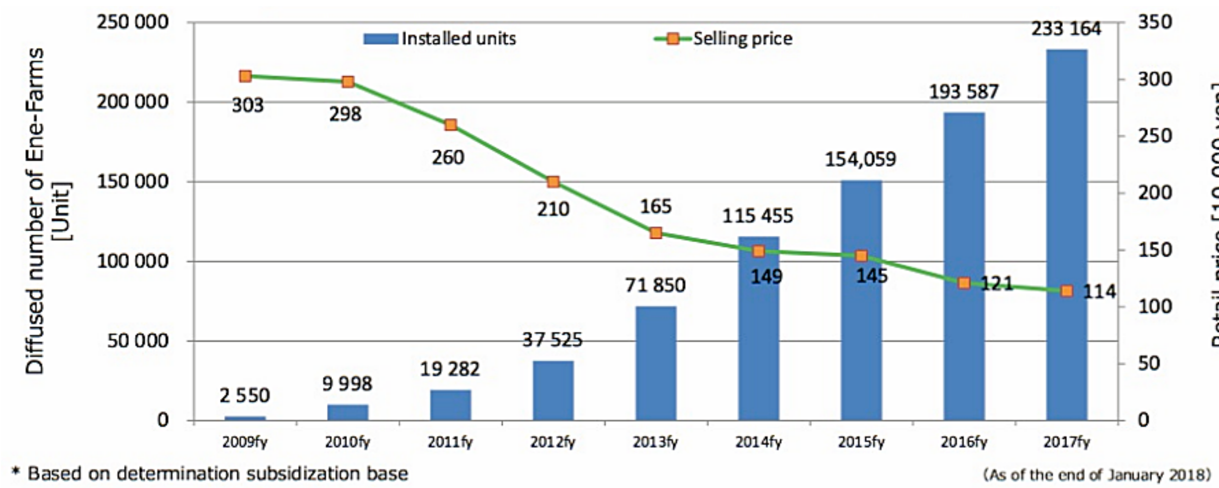

Figure 2. Locations of micro-CHP units demonstrated as of November 2016.

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 [9].

Real-life data from the field trial shows average electrical efficiencies of 37% for the SOFC systems and 32% for the PEMFC systems. Average thermal efficiencies are 46% for SOFC and 57% for PEMFC. It is important to mention that these are average values within all the systems installed and standard deviations are very high (for electrical efficiency, st. dev. is 30–59% for the SOFC and 48–66% for the PEMFC).

The second step of the European fuel cell based micro-CHP diffusion has been the ongoing PACE project (Pathway to a Competitive European FC mCHP market, 2016–2021). The project is on track to achieve its target of installing 2 800 fuel cell micro-CHP units in households across Europe by 2021. As of January 2019, more than 1 200 fuel cell units have been sold, nearly half of the project's target number. Last year saw significant increases in sales in several countries, with exponential growth in Belgium thanks to a favourable investment climate [10].

The only country where specific subsidies for fuel cell systems are available is Germany, where the Cogeneration Act was passed in 2002 and revised several times, most recently in January 2016. Here the fuel cell market appears to be in transition, somewhere between the pilot phase and market diffusion [2,11]. The programme [12] provides a grant between 7 050 and 28 200 € per fuel cell – depending on the electrical output of the fuel cell system – for installation in new or existing buildings, and for residential and non-residential buildings. Fuel cell are subsidized in the power range from 0.25 to 5.0 kW electrical power. The economic support could include the investment cost for the fuel cell system and its installation, the cost of the full maintenance contract in the first 10 years and the costs for the services of the energy efficiency expert.

A CHP-based Feed-in-Tariff was also available in the United Kingdom but was stopped in March 2019. Italy also has a cogeneration systems dedicated supporting scheme, which includes a relatively low price paid for the electricity produced and a reduction on the taxes paid on the natural gas fed to the system. Anyway, both the UK and IT supporting schemes were referred to generic micro-cogeneration systems and not specifically to fuel cell, as happening in the German case.

Fuel cell systems for the non-residential building sector

When discussing about opportunities for FC micro-CHP systems, the residential building sector is not the only accessible market. Non-residential building sector includes all the commercial activities and office buildings. This market is addressed in the framework of a dedicated European project, ComSos (Commercial-scale SOFC systems, 2018–2020). The project aims to validate and demonstrate fuel cell based combined heat and power solutions in the mid-sized power ranges of 10–60 kW, referred to as Mini FC-CHP. ComSos goal is the installation of 20–25 units in the mid-size power range, from 3 European producers (Convion Oy, SOLIDpower SPA and Sunfire GMBH). Unlike the PACE and Ene.field initiative, ComSos focuses only on SOFC systems, because of the superior advantages of the technology among the competitors (high efficiency and zero emissions). A dedicated market analysis was developed to define the best business cases for the installation of the SOFC system. Some results are presented below.

The main criteria for the selection of the best suitable market for the SOFC-CHP installation are the availability of a base load – essential to run the SOFC at a near-constant power output through the lifetime – and optimal energy prices (electricity price higher than NG price). The spark spread, defined - in this framework - as the difference between the electricity and natural gas prices (in €/kWh), is one of the key elements which is influencing the economic sustainability of the fuel cell installation (without any specific supporting scheme).

Supermarkets have been found as the best candidates for the installation of the FC-CHP system. For medium-large size supermarkets, it is possible to define a quite constant Energy Intensity in the range 600–800 kWh/m². A dedicated modeling of the SOFC system coupled with a typical supermarket (with hourly electrical and thermal profiles retrieved from [13]) has been developed in the framework of the project. **Figure 4** shows the results for a 60 kW SOFC module installed in a supermarket in different countries (with different consumption profiles depending on the location) in the hypothesis of a subsidized scenario. The most striking, even if expected, finding is the direct and strong correlation between the spark spread and the Relative Pay Back Time (RPBT), defined as the time in which the SOFC investment starts to become economically more convenient than the base scenario (electricity from the grid and heat from a natural gas boiler). The correlation between the energy prices difference and the economic performance of the investment is pointed out. Best markets for the SOFC installation are Italy, the UK, Spain and some US cities.

Conclusions

The status of fuel cell technology of the building sector worldwide is covered in the present work. Both landmark projects and supporting schemes are reviewed. The case of Japan shows how the diffusion of fuel cell based micro-CHP systems is feasible and that the optimal size for residential buildings lies in the range 0.4–0.7 kW electrical. In Europe, different EU-funded initiatives and German dedicated subsidies are pushing the market entry of these systems. The overall number of installed units in Europe still lacks behind the Asian numbers. However, results from demonstration projects gave credibility to the whole fuel cell sector showcasing the high performance of this concept and underlined criticalities on which producers should focus (cost reduction and improved lifetime). Increased sales should be encouraged by subsidies to 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 anticipated environmental and system benefits, while creating new jobs.

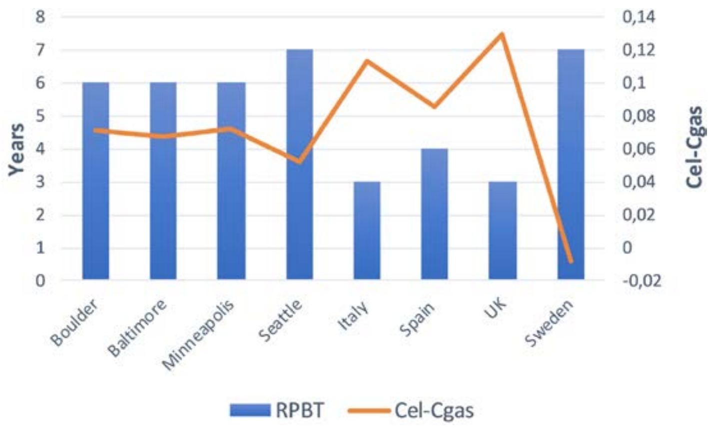

Figure 4. Results of the analysis of FC system installation in supermarkets.

On November 19th 2019, industry and stakeholders from the energy sector launched the Joint Declaration on Stationary Fuel Cells for Green Buildings to draw attention to the tremendous potential of stationary fuel cells to decarbonise the buildings sector. The signatories acknowledge that households and small businesses will play a vital role in the energy transition. With heating and cooling in buildings responsible for 36% of carbon emissions in Europe, they call for action to reduce our carbon footprint in the buildings sector with efficient, renewable and decentralised smart energy solutions. ■

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