Deliverable 6.13

Final report on market potential and business analysis

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Introduction

Project scope

The scope of the project is to develop and demonstrate a micro combined heat and power (CHP) system that would provide heat and electricity through a high-temperature proton exchange member fuel cell (HT-PEMFC) system. The EMPOWER system is intended to function as a back-up or off-grid solution in industrial and residential applications where the electricity produced it used for utilities and the waste-heat is used in space heating and domestic hot water purposes.

Purpose of document

This report marks the second instalment of a two-part series focused on the market potential and business analysis of developed HT-PEMFC based CHP system and the renewable methanol concept. Preceding this, D6.12 - Initial report on market potential and business analysis - was concluded prior to the mid-term review of the project.

The initial part of the business analysis focused on aspects such as the current micro-CHP market size, a comparative study of commercial products, and an exploration of the EMPOWER concept. Building upon these foundations, this deliverable extends the market analysis, broadening its scope to encompass CHP sizes ranging from tens of kW and beyond.

This document presents an analysis of the market for fuel cell micro-CHP systems. In addition to the typical, small systems of ~1 kW, larger systems of 50-100 kW and their potential deployment is discussed. The potential of micro-CHP systems in different sectors is identified. The emphasis is on the current potential and state of the micro-CHP market. In addition, advantages and characteristics of the methanol fuelled EMPOWER system are presented in comparison with other types of fuel cell micro-CHP systems.

Market analysis

Market potential

Potential markets for fuel cell micro-CHP systems

The market potential of fuel cell micro-CHP systems can be divided into three different categories: residential, commercial, and industrial potential. Currently, the residential market for fuel cell micro-CHP applications is the most established of the three categories, especially in Asia. One reason for this is the action taken in Japan. The Ene-Farm program, taking place in Japan, has resulted in over 400,000 installations of FC micro-CHP systems (Frost & Sullivan, 2022; Simader & Vidovic, 2022). The program is the largest worldwide deployment program for residential fuel cells. The fuel cell systems are relatively small and have a typical electrical power output of ~0.7 kW. The program includes both PEM and SOFC based systems (Simader & Vidovic, 2022).

The residential sector accounts for approximately 40% of the global final energy in buildings and industry. Space and water heating are significant parts of this energy use. Biomass and waste make up for more than 40% of the residential heating globally, mostly in less developed countries. Although, natural gas also contributes to a large portion, approximately 20%, of the global residential heat, mainly in OECD countries. Gas boilers are especially used for residential heat because of their safety, simplicity, and low cost (Dodds, et al., 2015). Although, current plans regarding renewable energy, in Europe especially, intend to phase out natural gas. One reason for this is Russia's invasion Ukraine which has resulted in a limited gas supply and high prices. The other reason is the intention to phase out natural gas to decrease the greenhouse gas emissions and limit the use of fossil fuels. Therefore, fuel cell micro-CHP systems could help to decarbonize the residential heating sector but also decrease the current fossil fuel dependency of heating solutions. Currently, the renewable fuel contribution in the heating sector consists mainly of biomass (Dodds, et al., 2015), which can be difficult to scale up sustainably. Therefore, fuel cell -based solutions could have potential to expand the use of renewables within residential heating solutions. In addition, fuel cell micro-CHP systems emit close to zero of local emissions, such as NOx or SOX emissions (Gandiglio, et al., 2020). Fuel cell micro-CHP systems generally have a higher electrical efficiency than other micro-CHP systems, which makes them suitable especially for residential applications (Ellamla, et al., 2015).

Space and water heating constitutes to a significant part of the energy demand in commercial and public buildings, as in the residential sector. Unlike in residential buildings, commercial buildings have a lot more alternative solutions when it comes to heating. There is a lot of variation within the commercial sector on building sizes and shapes, depending on the application. The relative fuel consumption is lower than in the residential or industrial sectors and therefore the decarbonization is potentially easier. The dominant solutions for heating are electricity and natural gas. Large commercial buildings often include HVAC systems that could be run simultaneously with fuel cell CHP systems. Although, there are some barriers that might prevent from fuel cell micro-CHP systems of penetrating the market. First barrier is the fact that there are not necessarily enough incentives since the commercial sector is not as carbon intensive as the residential and industrial sectors and hence does not have a similar need for change. Other barriers for fuel cell micro-CHP deployment include high system costs and the reluctance of deployment of innovative solutions (Dodds, et al., 2015).

The industrial demand for heat is distinct compared to heat demand in residential and commercial applications because it is quite large compared to end use demand. Mostly fossil fuels, including coal, natural gas and petroleum products, are used to generate heat for industrial purposes. Industrial heat demand has a great variation on required temperature levels (IEA, 2018; Dodds, et al., 2015). The total global industrial heat demand is 107 EJ (IEA, 2022; Dodds, et al., 2015), of which about 22.1 EJ corresponds to heat demand of 100-200 degrees Celsius (IEA, 2022), which is the temperature range of a high temperature PEM fuel cell systems, such as the EMPOWER system.

It is pointed out in (Dodds, et al., 2015) that largest potential markets are found from the residential and industrial sectors because they have the most to decarbonize. These two are also the intended applications for the EMPOWER system. The commercial sector has more variation in applications since commercial and public sector building come in many different shapes, sizes, and have different heat demands.

Market potential of fuel cell micro-CHP systems versus other micro-CHP systems

The main types of micro-CHP systems are the internal combustion engine (ICE), Stirling engine, and fuel cell micro-CHP technologies. ICEs are essentially diesel engines that run with natural gas or oil and are connected to electrical generators. The cooling water and exhaust gas of the engine is used for heating needs. Stirling engine CHP is practically a regular boiler with an in-built Stirling engine, which is an external combustion engine. When the boiler is used, this external combustion engine heats up and the gas within the Stirling engine expands and is used to produce electricity (Energy Saving Trust, 2022).

ICEs are the most common types of commercial micro-CHP systems (Gandiglio, et al., 2020; Ellamla, et al., 2015). This is mainly because they are available commercially and are also the cheapest micro-CHP system available (Ellamla, et al., 2015). Although, the gap in the costs of fuel cell CHP systems and conventional CHP systems has been narrowing (Dodds, et al., 2015). Fuel cells generally have a better electric efficiency than the other micro-CHP types, hence the other micro-CHP types are better suited for applications that require larger heat loads. The high electrical efficiency makes fuel cell micro-CHP systems more suitable for residential applications, as stated previously (Gandiglio, et al., 2020; Ellamla, et al., 2015).

One of the benefits of a fuel cell micro-CHP system is the fact that it can replace fossil fuel - based systems and to decarbonize the heating sector. Natural gas is being phased out, especially in Europe, which could result in ICE micro-CHP systems being a less attractive option for deployment. Although it is important to note that the emissions of a fuel cell system are minimized when used with a renewable fuel. In addition, the CO_2 emission savings depend heavily on the country and heating system. According to (Ellamla, et al., 2015), a residential fuel cell micro-CHP system of 1 kW could reduce household emissions by 1.3-1.9 t/CO_2 per year in Japan and Germany. Larger systems could result in more emission savings than smaller, residential systems. The carbon intensity of the electricity produced with a fuel cell micro-CHP system is approximately a third of the intensity of a coal plant and a half of a natural gas plant (Ellamla, et al., 2015). In addition, fuel cell micro-CHP systems have an advantage over the combustion based micro-CHP systems because they emit close to zero of the local emissions, such as NOx or SOX emissions (Gandiglio, et al., 2020).

Potential of 50-100 kW fuel cell micro-CHP systems

The potential of slightly larger CHP systems of size 50-100 kW lies in larger non-residential buildings, such as supermarkets, malls, hotels and hospitals, rather than in residential buildings. This is because larger systems are better equipped with providing constant heat to larger non-residential buildings with stable heat loads. Residential buildings, on the other hand, have a lot of variation in the load during the day. Therefore, the load is often larger in non-residential buildings (Gandiglio, et al., 2021). Industrial applications could also be suitable for larger fuel cell micro-CHP systems since they have a lot of variation in the heat demand, as discussed previously.

As pointed out by (Simader & Vidovic, 2022) the economic performance of fuel cell micro-CHP systems increases with higher power output systems with long operating hours. Larger systems are generally cheaper because of economies of scale (Dodds, et al., 2015). This could be beneficial for larger fuel cell micro-CHP systems in case they are able to achieve larger cost reductions than smaller systems. Although smaller systems have been deployed in larger amounts than larger systems, especially in residential applications. The increasing installations of ~0.7-1 kW PEM and SOFC micro-CHP systems during the Ene.Farm project in Japan have resulted in significant cost reductions. With over 230,000 installations in 2017 the costs have decreased from 24 900€ to 9400€ per unit during the years 2009-2017 (Gandiglio, et al., 2020).

EMPOWER versus other fuel cell micro-CHP systems

Methanol as a fuel in fuel cell micro-CHP systems

The EMPOWER micro-CHP system uses methanol as a fuel. It is easier to transport than hydrogen because it is a liquid at room temperature and atmospheric pressure. Therefore, no additional energy is required for the pressurization unlike with of hydrogen. These factors make methanol an appealing option for a fuel.

One of the main benefits of a fuel cell system is the fact that it cuts down on the emissions compared to ICE or Stirling engine micro-CHP systems. Although, the methanol used in the system should also be renewable to ensure that the system itself cuts down on emissions.

Currently, methanol is produced almost fully from fossil sources, only 0.2% of production being renewable. As much as 65% of the total methanol production is produced by reforming natural gas while the remaining 35% is produced through coal gasification. Renewable methanol can either be bio-methanol that is produced from biomass or e-methanol that is produced from captured CO_2 from renewable sources and renewable hydrogen produced from electricity (IRENA & Methanol Institute, 2021). Most of the produced renewable methanol is bio-based and only a small fraction is e-methanol (IRENA & Methanol Institute, 2021; Methanol Institute, n.d.).

Resulting from Russia's invasion of Ukraine, the natural gas prices have peaked. This has caused the methanol production in Europe to suffer since close to 40% of Europe's annual gas consumption has come from Russia. Currently, over 30% of European methanol production is either offline or operating at a lower capacity. Europe is at a competitive disadvantage because of the shortage of natural gas supply. Asia and the middle east have lower cost supply of methanol (ICIS, 2022).

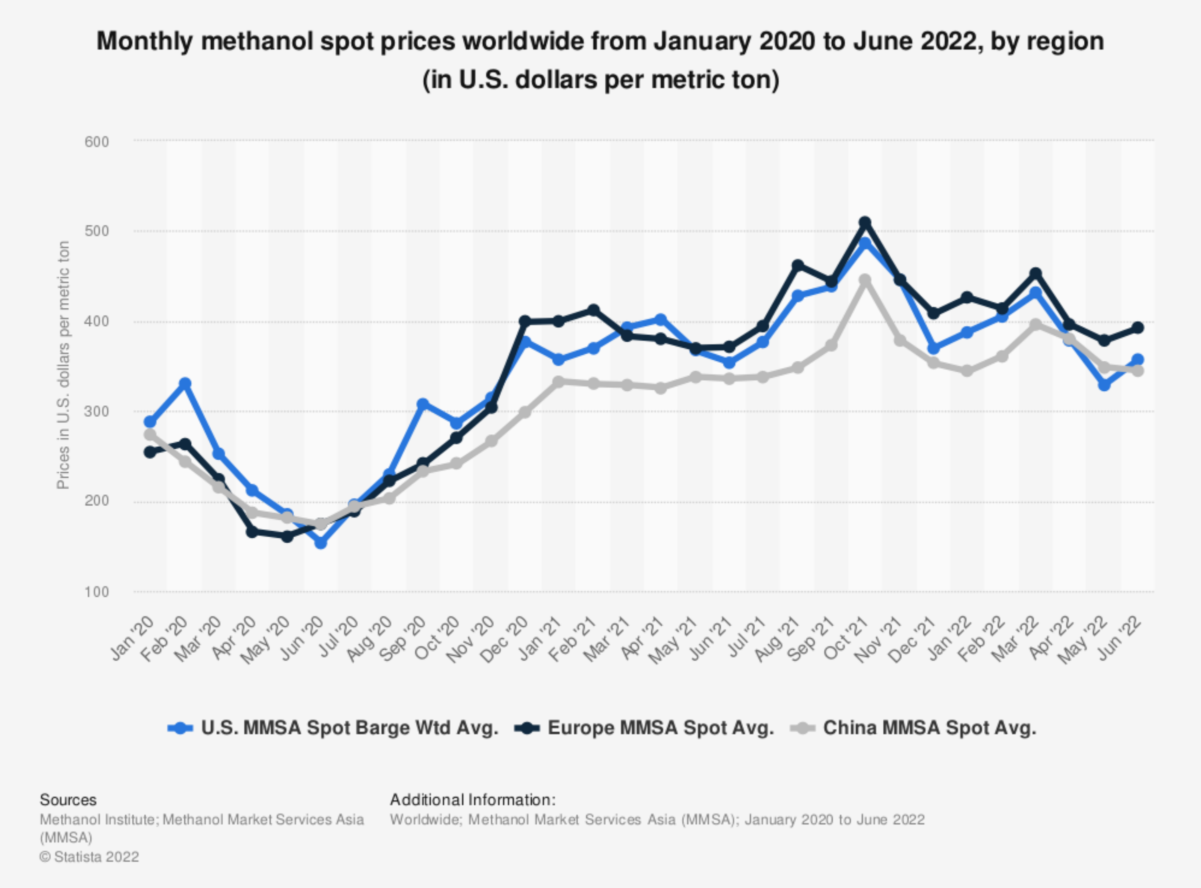

Figure 1. Monthly methanol spot prices worldwide by region.

As presented in the previous deliverable (Deliverable 6.12 – Initial report on market potential and business analysis), the renewable methanol production pathways are not quite yet competitive. The current production cost of bio-methanol is around $330-1000/t and $820-2400/t for e-methanol (IRENA & Methanol Institute, 2021). Despite the difficulties in fossil methanol production, especially in Europe, methanol price has not increased significantly and is on a level of $300-400/t as seen in Figure 1 (Methanol Institute, 2022). Therefore, costs of renewable methanol production should decrease for it to be competitive with non-renewable methanol. The costs are predicted to decrease in the future with production technology maturity, but cost competitiveness can also be achieved when cheap renewable energy is present. A good example of this is the George Olah plant in Iceland. It is a commercial CO2-to-methanol production plant that produces e-methanol. It started operating in 2011 and is operated by CRI. It is the first commercial e-methanol producing plant that has a production capacity of 4000 tonnes per year. One reason why it is a successful project is because cheap geothermal energy is used in the water electrolysis process (IRENA & Methanol Institute, 2021).

HT-PEMFC versus other fuel cell systems

The EMPOWER system is a high temperature PEM fuel cell (HT-PEMFC) system. Currently PEM fuel cells are the most developed fuel cell technology, making up around 90% of total system sales. The remaining 10% of systems sold globally are SOFC systems. PEM systems can operate dynamically, therefore they are widely used in residential applications. SOFC systems are used both in large industrial CHP applications but also residential heating systems. Although, SOFC systems are not as flexible as PEM systems and their start-up and shut-down can take up to 12 hours or more, requiring a hot temperature during start up. Therefore, applications that do not require flexible operations are better suited for SOFC. This includes applications that have a constant electrical and heating load, such as several commercial and industrial applications (Dodds, et al., 2015).

PEMFCs tend to be low-temperature PEMFCs (LT-PEMFCs), but in the recent years high-temperature PEMFCs (HT-PEMFCs) have gained more attention because of their advantages including easy water and heat management and good carbon monoxide tolerance (Lee, et al., 2022). HT-PEMFC is seen as a good alternative to LT-PEMFC because of the performance improvements and cost reduction it can achieve (Ellamla, et al., 2015). Although, HT-PEMFC requires improvements regarding internal local temperature instability, flow rate, and pressure variation which lead to accelerated aging of the membrane electrode materials and, therefore, degradation (Lee, et al., 2022).

When it comes to fuel cell micro-CHP systems, SOEC and PEM are the types of fuel cells that are largely discussed and developed. Other fuel cell systems, include the phosphoric acid fuel cells (PAFCs), the molten carbonate fuel cells (MCFCs), and alkaline fuel cells. PAFCs have concentrated phosphoric acid as the electrolyte and platinum as both electrodes while in MCFCs the electrolyte is made of a molten carbonate salt mixture and the electrodes contain non-precious metals (Popel, et al., 2018; Ellamla, et al., 2015). They are not used in micro-CHP applications since they are not quite suitable for residential applications but rather large-scale applications, including power plants (Ellamla, et al., 2015; Dodds, et al., 2015). Alkaline fuel cell systems, on the other hand, are not used as domestic micro-CHP applications because of their issues with durability and CO_2 contamination issues (Ellamla, et al., 2015).

Larger micro-CHP systems, especially when integrated with non-residential buildings, could be better suited for SOFC systems instead of PEMFC systems. This is because of the beforementioned load profile. Non-residential buildings have a constant load and heat demand which is beneficial for SOFC systems since they have a high efficiency and are not as that well integrated with varying load because of the long start up time especially with cold start up (Gandiglio, et al., 2021).

Market barriers

One significant barrier that prevents wider technology uptake of micro-CHP systems is the high CAPEX (Monforti Ferrario, et al., 2021; Dodds, et al., 2015; Frost & Sullivan, 2022). The current CAPEX for micro-CHP systems is around 11,000 €/kW (Gandiglio, et al., 2021). Although, the CAPEX varies with fuel cell type and location. The broader range where most micro-CHP systems fall is from 10,000 €/kW to several tens of thousands of euros per kW (Gandiglio, et al., 2021; Staffell, et al., 2019; Dodds, et al., 2015). Some of the cheapest systems are found in Asia (~£12,000-16,000 per 0.7 kW system), while the European systems are more expensive (~£26,000/system). In residential systems the cost is mostly determined by the CAPEX and the stack replacement cost. According to one estimate, residential micro-CHP systems could be cost competitive when compared to conventional solutions between 2025-2050 (Staffell, et al., 2019). Although, it is worth noting that CAPEX is a barrier especially in very small systems and increased production capacity together with increased installation amount are projected to decrease costs (Gandiglio, et al., 2021; Gandiglio, et al., 2020). As an example, Japanese demonstration projects have shown that the price of fuel cell micro-CHP systems can be decreased by approximately a fourth by doubling the production and commercialization could further decrease the cost by approximately 13% (Ellamla, et al., 2015).

Since fuel cell micro cogeneration is quite expensive at the moment subsidies could help with deployment and lower market barriers. Options for subsidies are capital investment subsidies, feed-in tariffs, and energy efficiency certificates. According to (Gandiglio, et al., 2021), feed-in tariffs seem to be the most potent option at the current economic situation. Feed-in tariffs could make the use of micro-CHP systems feasible by supporting the produced energy units by a fixed about of money per kWh (Gandiglio, et al., 2021; Dodds, et al., 2015). They have previously helped to bring solar PVs to the market (Dodds, et al., 2015). Germany, Italy and the UK are most suitable markets for fuel cell micro-CHP systems (SOFC) because of their existing policies to support CHP production and the high share of CHP in the national energy production. Although, the UK seems to be the only market that could achieve a relative payback time of 10 years with current cost levels because of the suitable feed-in tariff of 11 c/kWh. The relative payback time is obtained by calculating the amount of years it takes for the cumulative cash flow to be positive. In the US, as a comparison, the installation costs are too high to achieve a payback time of less than 15 years with current subsidies (Gandiglio, et al., 2021).

With commercial buildings, a barrier of deployment of fuel cell micro-CHP systems is the possible reluctance of organizations to adopt innovative technology. This is because of technological immaturity (Dodds, et al., 2015; Frost & Sullivan, 2022). Systems based on conventional systems, including natural gas, have been more common because of their reliability. Although especially Europe is currently trying to phase out Russian natural gas because of the war in Ukraine. This could result in an increased desire to invest in more innovative, renewable solutions, including fuel cell CHP systems.

Barriers to the deployment of fuel cell micro-CHP technologies also include technology immaturity. This is the case for especially SOFC systems, which are in a pre-commercial state. SOFC systems have had issues with lifetime and durability, but they have improved significantly in the past years (Dodds, et al., 2015; Gandiglio, et al., 2021).

Summary

Currently micro-CHP systems are mostly used in residential applications which is the most potential market. Fuel cell micro-CHP systems could also be used in industrial applications since the energy demand is large with a lot of different temperature ranges. Commercial buildings could also be integrated with micro-CHP solutions but the available solutions to heating and power demand are already flexible with a lot of reliance on electricity-based solutions. Therefore, the potential of micro-CHP integration to commercial buildings is slightly smaller than for residential and industrial markets that are highly reliant on fossil fuels.

Larger micro-CHP systems (~50-100 kW) are better suited for applications with a large, constant heat load, such as commercial buildings. SOFC systems in particular are a good fit for these kind of larger systems because of the high efficiency and constant lead. On the other hand, small systems of around 1 kW are well suited for residential applications because the load varies throughout the day and heat demands are not likely to be as large. PEM systems are the dominant technology in residential applications. High-temperature PEM systems, such as the EMPOWER system, have been a point of interest recently because of the potential in cost reductions and performance improvements in comparison to the low-temperature PEM systems.

The EMPOWER system is powered by methanol, but currently, renewable methanol only contributes to a small fraction (0.2%) of the current total methanol production. Renewable methanol production pathways are not yet competitive with the conventional production from natural gas, but their costs are likely to decrease in the future when the technology matures. Bio-methanol production is closer to the conventional production cost level than e-methanol, but cost reductions are required with both pathways. Future plans to phase out natural gas could not only help with increasing the attractiveness of micro-CHP production but also renewable methanol production.

Barriers to deployment of fuel cell micro-CHP systems include high cost and technology immaturity which can hinder the deployment. The capital cost of the system can be decreased with increased system installations, as seen in Japan. Although, system deployment attractiveness is likely to increase with technology maturity. In addition, subsidies, such as feed-in tariffs, can be used to accelerate the deployment process. Renewable options in general are also likely to be more attractive in the future with the beforementioned plans to phase out fossil fuels.

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