2021

Stationry Fuel Cell Applications

Tracking Market Trends

V. CIGOLOTTI, M. GENOVESE

IEA Technology Collaboration Programme
Advanced Fuel Cells

Technology Collaboration Programme
by iea

STATIONARY FUEL CELL APPLICATIONS: TRACKING MARKET TRENDS

V. Cigolotti*, M. Genovese**
* ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Research Centre of Portici, Naples, (*Italy*)
**University of Calabria, Department of Mechanical, Energy and Management Engineering, Arcavacata di Rende, 87036 Cosenza, (*Italy*)

Abstract – Fuel cell systems are becoming key technologies, worldwide recognized as society decarbonizing energy systems. The present report aims to analyze the worldwide rolling out of these technologies, with a deeper analysis for PEM and SOFC, since they result to share the most predominant rates in the market. For the micro-CHP market, Japan and Europe are leading the market and the R&D activities, thanks to ad-hoc subsides and programs. Japan results to be the main leader in CHP installations thanks to the ENEFARM program with more than 314,000 fuel cells installed, where the price per sale has been decreased to US$7,000/unit for PEM and US$8,800/unit for SOFC. Europe is keeping pace with Japan, with 4,100 of CHP units installed, thanks to three main actions (Callux, PACE and ene.field).
For larger stationary applications, USA is leading the picture, with a cumulated installed capacity of 500 MW.

1. INTRODUCTION

Fuel cell technologies allow several applications in stationary power production, such as primary power, grid stabilization, backup power and combined-heat-and-power configurations (CHP).

The main sectors, where stationary fuel cells have been employed, are (a) micro-CHP, (b) large stationary applications, (c) UPS and IPS. The fuel cell size for stationary applications is strongly related to the power needed from the load. Since these sectors range from simple back-up systems to large facilities, the stationary fuel cell market includes few kW and less (micro-generation) to larger sizes of some MW.

The design parameters for the stationary fuel cell system differ for fuel cell technology (PEM, AFC, PAFC, MCFC, SOFC), as well as for the fuel typology and supply [1].

According to 6Wresearch [2], the global market of stationary fuel cells is going to reach high levels of growth in the next years (2019-2025).

In 2018, the world fuel cell market has been characterized by a markable growth in Fuel Cell Shipments [3]: the overall shipment units increased to 57.500, with a total power of 240 MW. Compared to the situation in 2017, the market has registered a 5% increase on the shipments and 8% on the installed power. A better picture is noticeable if 2018 market is compared to 2012 situation: fuel cell shipments in 2012 resulted to be 125 MW, that means in 2018 the market has lived an increase of 92 % in comparison to 2012 [4].

The value of the market has been estimated at US$1.8 billion in 2018, and a current study reported that this market is projected to increase to US$2.2 billion by the end of 2019 [4,5].

According to "Research and Market, 2019" [6,7], the stationary fuel cell market will grow up to US$5.08 billion by 2030, with a Compound Annual Growth Rate (CAGR) increase of 3.9%. The total installed capacity is forecasted to grow from 220 MW to 612 MW, and the market will be led by US in North America and Japan (and China in the near future) in Asia.

As reported in the "Solid Oxide Fuel Cell - Global Market Outlook (2017-2026)" [8] SOFC technology had an important market share in 2017, accounting for US$389.21 million in 2017, and it is forecasted to increase up to US$1356.51 million by 2026, with a CAGR of 14.9%. In North America, it is expected to grow with CARG of more than 13% by 2023, in Europe and Asia-Pacific of 15%, 13% in South America and MEA [9]. With a lower market share, but with an important trend, Direct Methanol Fuel Cells have been valued US$137 million in 2018, expecting to grow up to US$367 million by 2025 [10,11] .

Supportive government policies, economy of scale and technology improvements are the main drivers of this important growth.

Several prototypes, experimental projects and proof-of-concept are executed and validated, allowing a deeper understanding of the technology performance under real operating conditions. The fuel cell equipment adopted and installed is reported to have a range of power between 0.5 kW to 400 kW [12,13].

Within, these projects applied to stationary applications [14], different configurations and end-user-applications have been tested, namely as "back-up power supplies, power generation for remote locations, stand-alone power stations for one or more consumers, distributed generation for buildings and cogeneration" [15].

2. SITUATION IN THE WORLD

Depending on the fuel cell typology, fuel cell companies are consolidated in different countries. As listed in the appendix, most of the big players are located in Europe, Japan and the USA. All three main technologies (MCFC, SOFC, PAFC) are active and manufactured in the US, above for bigger sizes. In fact, depending on the size applications, the market is dominant in different countries. Japan and Europe have lower installation numbers of stationary large-scale fuel cell installations, while in South Korea PAFC and MCFC are the most installed technologies.

For the residential micro-CHP applications, Europe and Japan are leading the market, thanks to ad hoc aimed subsides and programs.

Europe has installed more than 4,100 of CHP units [16], thanks to three main actions [17]: Callux, PACE and ene.field. The three programs have been key actions for the technology roll out. Only in the ene.field program, 603 PEM and 403 SOFC micro-CHP units have been installed. In Germany, an incentive program (KfW) [18,19] is supporting micro-CHP early market, at different levels: 5,700 € as fixed amount for a new fuel cell, and other additional amounts and flat-rate supplements. For every 100 Watt of electrical power started, another 450 € are added, up to 6,750 €. When used in CHP mode, a subsidy is paid for each kilowatt hour of electricity produced: 4 Ct/kWh for electricity that is consumed and 8 cents for electricity that is fed into the grid [20]. The program aims to provide funding for the installations of about 60,000 CHP units by 2022 [21]. Current costs of fuel cell micro-CHP in

Europe is about €13,000/kW, with more than 2,000 micro-CHP fuel cell based adopted on field, and another 2,500 planned until 2021 [22]. Largest stationary fuel cell power plant currently operating in Europe provides 1.4 MW.

Japan in the main leader in CHP installations, with the ENEFARM program. They have been able to decrease the price to US$7,000/unit for PEM, and US$8,800/unit for SOFC [3,23]. The overall installations can be added up to 260,000 units, almost 62% of them are PEMFC, 38% SOFC. The program offered also subsides, from the 50% of the cost, to US$730/unit for SOFC and no-more subsides for PEMFC, since the commercial price could now be competitive.

Asia resulted to be the more active area in installing fuel cell units, above all for commercial micro-CHP application, particularly in Japan in the last five years, which have experienced an increase of almost 30% in 2018 (55,500 installed units) in comparison to 2014.

Most of the USA market is based on SOFC (300 MW installed), with subsides between 600-1,200 €/kW (NG or Biogas), and a price per sale of 10,000 US$/kW. PEMFC large installations in the USA are still few (10 MW) compared to other technologies.

Europe counts 1.8 MW of SOFC systems and 1.5 MW of PEMFC, with 34 million Euro available under Horizon 2020 program for stationary fuel cells.

Korea has 1.5 MW installed of PEMFC systems, considering that Hyundai NEXO stack is used stationary, too. Subsides up to 80% of the costs for demonstration projects are helping these innovative technologies spreading out. Japan has 2.5 MW of PEMFC installed, and research and development are considered key actions, since US$300-400 million are available for R&D on Stationary FC.

For the other fuel cell technologies, MCFC are leader on large stationary applications, as shown in Table 1.

Country/State	Technology	Cumulated Installed Capacity [MW]	Subsides	Price per sale [€]
USA	MCFC	150	600-1200 €/kW (NG or Biogas)	8000-9000 US$/kW
Europe	MCFC	13	34 M Euro, Horizon 2020 for Stationary FC	NA
Korea	MCFC	150	NA	NA
Japan	MCFC	6	US$300-400 M for R&D on Stationary FC	NA
RoW	MCFC	NA	NA	NA
USA	PAFC	50	NA	NA
Europe	PAFC	1	34 M Euro, Horizon 2020 for Stationary FC	NA
Korea	PAFC	130	up to 80% of the costs for demonstration projects	NA
Japan	PAFC	8	US$300-400 M for R&D on Stationary FC	NA
RoW	PAFC	NA	NA	NA

TABLE 1: MCFC AND AFC INSTALLATIONS, RETRIEVED FROM [24]

3. Fuel Cell Installations

Figure 1 summarizes the shipments per fuel cell type. While PEMFC seem to have a steady decreasing trend, the market is showing big efforts to strengthen SOFC, since their better performance and wide range applications. DMFC are used for both, mobile and stationary applications, while AFC and MCFC had very few installations. However, their size resulted to have a higher installation size, as highlighted in Figure 2. MCFC installations in 2018 resulted to be sligthly more than 25 MW. Even if the number of PEM installations is decreasing, their installation size is increasing, signal of their technology maturity. AFC installations are infrequent, while Korea has the leadership on PAFC installations. PEM fuel cells are used in several applications (both stationary and mobile applications), and they contribute to the highest number of installed capacities.

SOFC (more shipments at lower size) and PAFC (low shipments at higher size) had a slow implementation in 2014, but their trend is increasing. MCFC had a high research interest in 2014, at higher sizes, but the trend is now decreasing.

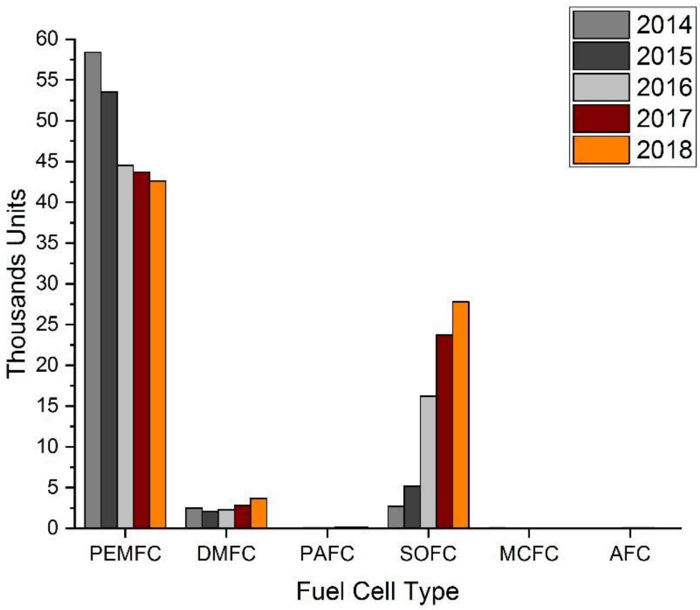

Figure 1: Fuel Cell Shipments, retrieved from [3]

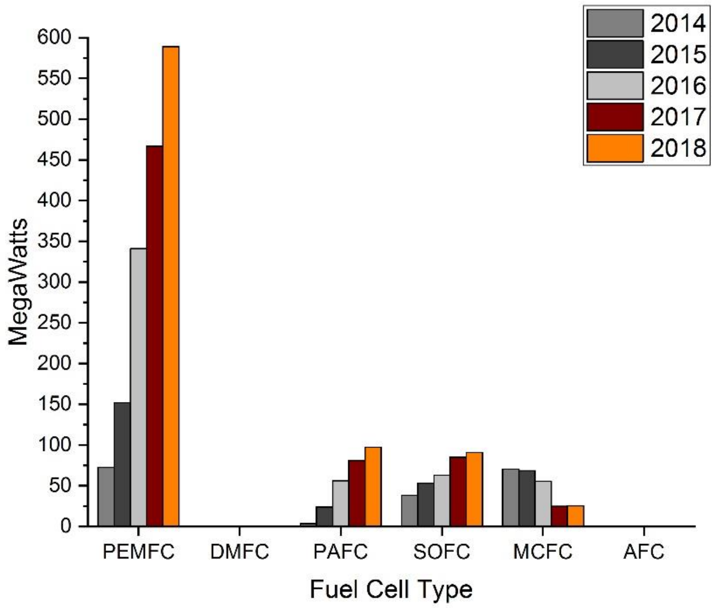

FIGURE 2: FUEL CELL SIZE INSTALLATIONS, RETRIEVED FROM [3]

4. NICHE MARKET APPLICATIONS

Other niche market applications based on fuel cell technologies are BUP and UPS, as well as hydrogen boilers using catalytic burners/hydrogen gas turbines. For the latter, few data have been found, since the market is still too small.

Hydrogen Europe [25] has drafted a roadmap for hydrogen related new technologies and R&D actions, since they could reveal themselves as the best options when CHP installations are not economically viable. For UPS, in the IEA Hydrogen and Fuel Cells roadmap [12], small uninterruptible power systems for back-up power are considered key factors for autonomous power systems for either stationary or portable off-grid applications, but few commercial applications have been found. Larger uninterruptible power supplies have been installed, as described in the report [13], up to around 5 MW for uninterruptible power, in California, reflecting the importance of for data centers, banks, hospitals and similar organizations.

An estimated over 3,000 of these systems were deployed until 2019 [26].

The mobile telecommunication industry is an example for a sector that needs back-up and off grid power, with an estimated number of 7 million stations worldwide, increasing every year by 100,000. For these applications, fuel cells can offer more reliable and stable operations, since their resilience to harsh environmental conditions rather than batteries, without the need of cooling [13].

An alternative to CHP fuel cell systems, hydrogen boilers for homes and commercial or public buildings can represent a valid option during the transition towards a 100% hydrogen economy. Building's energy demand shares a third of the global energy demand (118 EJ), and according to the latest report of the IEA, also a quarter of the global carbon dioxide emissions (slightly more than 8.5 Gt).

According to the Hydrogen Council [27], hydrogen boiler costs could drop within a range of US$900-1,600 until 2030, achieving competitive values closed to traditional natural gas boilers. Their installation and applications could be more penetrable since hydrogen injection can utilize the already-builts of the natural gas infrastructure, such as pipelines and boilers themselves. Applications in new buildings or in older buildings are viable, but their competiveness, as highlighted in Hydrogen Council's report, is strongly related to hydrogen production costs and supply chain: with a hydrogen cost of 5.4 US$/kg, the technology can be competitive with heat pump installations in older residences, while at 3 US$/kg hydrogen boilers become competitive with biomethane, too, for new buildings. At lower values, such as 1 US$/kg, the technology outcompetes natural gas, too, even if massive actions are needed to achieve such scenarios. Similar results have been reported in Hydrogen Europe's report [22], with a vision of hydrogen prices at 2 €/kg or below by 2030, with more than ten European regions implementing 100% hydrogen gas both for residential and industrial sectors.

Recent research trends are pursuing the possibility to blend green hydrogen into natural gas pipelines up to 20% in volume. Current levels are about 5%, assuring indeed between 32-58 kg of avoided carbon dioxide emissions per year and household. In other cases, some countries are allowing, under certain circumstances, injections up to 9-10% in volume [28].

In view of the 100% hydrogen scenario, pure hydrogen CHP-fuel cell based can become competitive and viable from a financial point of view, most likely by 2030 when hydrogen costs are forecasted to drop to 1.9 US$/kg [27], with a system specific cost of 2,700 US$ per household. Another option for hydrogen feeding and application is for hydrogen-fired combined-cycle gas turbines, already tested in Italy and in Japan, providing electricity and heat [13].

5. Conclusion

The present report analyzed the country-level data on current sales and stock of stationary fuel cells, both for micro-CHP and for large applications.

The analysis highlighted how PEM and SOFC share the most predominant rates in the market. For the micro-CHP market, Japan and Europe are leading the market and the R&D activities, thanks to ad-hoc subsides and programs. Japan resulted to be the main leader in CHP installations, with the ENEFARM program. They have been able to decrease the price per sale to US$7,000/unit for PEM, and to US$8,800/unit for SOFC. Europe is keeping pace with Japan, with 4,100 CHP units installed, thanks to three main actions (Callux, PACE and ene.field).

For larger stationary applications, USA is leading the pictures, with a cumulated installed capacity of 500 MW. MCFC present a high share in the America fuel cell market among the operating multi-MW fuel cell plants. PAFC are most predominant in Korea, since it is the home country of most of the PAFC manufacturers.

BUP/UPS and hydrogen boilers commercial data resulted to be few, since the market is probably still too small, and a deeper analysis is needed to track the trend.

6. Appendix: FC big players around the world

Region	Company	Field of Interest	FC Type
Canada	Hydrogenics	Hydrogen	PEMFC
Europe	Hexis	Hydrogen, natural gas, city gas, biogas	SOFC
Europe	Siemens Power Generation, Inc	H2 + CO, natural gas, jet fuel, diesel fuel	SOFC
Europe	Nedstack	Hydrogen	PEMFC
Europe	MTU CFU Solution	Waste gas, LP gas natural gas	MCFC
Europe	Ansaldo Fuel Cell	Waste gas, LP gas natural gas	MCFC
Europe	SolidPower	Natural gas, bio-methane	SOFC
Europe	AFC Energy	Direct hydrogen or cracked ammonia	AFC
Europe	AFC Energy	Direct hydrogen or cracked ammonia	AAEMFC
Europe	EFOY	Methanol	DMFC
Europe	Intelligent Energy	Hydrogen	PEMFC
Europe	Helbio SA	Natural Gas, Biogas, Propane/LPG, Ethanol	PEMFC
Europe	H2Planet	Hydrogen	PEMFC
Europe	EFOY	Hydrogen	PEMFC
Europe	Sunfire Fuel Cell	LPG / Propane or natural gas, biogas	SOFC
Europe	CeresPower	City Gas	SOFC
Japan	Mitsubishi Hitachi Power Systems	City gas	SOFC
Japan	Panasonic	Natural Gas	PEMFC
Japan	Aisin	Natural Gas	SOFC
Japan	Kyocera	utility-supplied gas or liquid petroleum (LP) gas	SOFC
Japan	Toshiba	Petroleum gas, biogas, town gas	PEMFC
Japan	Ishikawajima-Harima Heavy Industries (IHI)	Ammonia	SOFC
Japan	Ishikawajima-Harima Heavy Industries (IHI)	Waste gas, LP gas natural gas	PEMFC, MCFC
Japan	Fuji Electric	City gas, Biogas, Pure hydrogen	PEMFC, PAFC
Rep. KOREA	Posco Energy	LNG, Biogas, SNG	MCFC
USA	Technology Management, Inc. (TMI)	Natural Gas, Biogas, Propane/LPG, Ethanol	SOFC
USA	GenCell	Waste gas, LP gas natural gas	MCFC
USA	Power Innovations	Hydrogen	PEMFC
USA	Adaptive Energy	Natural Gas, Propane	SOFC
USA	Altergy	Hydrogen - Methanol	PEMFC
USA	Atrex Energy	Natural Gas, Propane	SOFC
USA	Bloom Energy	Natural Gas, Directed Biogas	SOFC
USA	Doosan Fuel Cell America	Natural Gas	PAFC
USA	FuelCell Energy	Natural Gas	MCFC
USA	Plug Power	Hydrogen	PEMFC
USA	Watt Fuel Cell	Natural Gas	SOFC
USA	Fuel Cell Technologies (FCT)	Biogas, natural gas, methanol	PEMFC, PAFC, DMFC
USA	Ballard Power Systems	Hydrogen	PEMFC
USA	FuelCell Energy	Biogas, natural gas, methanol	MCFC-SOFC
USA	UTC Power	Natural Gas, Hydrogen	PAFC - PEMFC
USA	H-Power Corp.	Natural gas, hydrogen, propane	PEMFC
USA	IdaTech	Natural gas, propane, methanol	PEMFC

7. Acknowledgment and Disclaimer

Scientific discussions with experts from the Advanced Fuel Cells Technology Collaboration Program, part of IEA´s Technology Platform, are gratefully acknowledged.
The AFC TCP functions within a framework created by the IEA. The activities of the AFC TCP were coordinated by the IEA´s Working Party on Energy End-use Technologies (EUWP). The views, findings and publications of the AFC TCP do not necessarily represent the views or policies of the IEA Secretariat or of its individual member countries.

8. References

[1] Herrmann A, Mädlow A, Krause H. Key performance indicators evaluation of a domestic hydrogen fuel cell CHP. Int J Hydrogen Energy 2019. doi:10.1016/j.ijhydene.2018.06.014.
[2] 6Wresearch. Global Stationary Fuel Cell Market. 2019.
[3] David Hart, Franz Lehner, Stuart Jones, Jonathan Lewis MK. The Fuel Cell Industry Review 2018. E4tech 2018.
[4] David A (Office of I. U . S . Manufacturers among Leading Suppliers in Growing Stationary Fuel Cell Market. 2019.
[5] Fact.MR. Stationary Fuel Cell Systems Market Forecast, Trend Analysis & Competition Tracking - Global Market Insights 2018 to 2027. 2018.
[6] Research and Market. Research and Markets, 2019. 2019, http://www.globenewswire.com
[7] Stationary fuel cells market, 2019-2030 - global market projected to reach US$5.1 bn by 2030. Focus Catal 2020;2020:2. doi:10.1016/j.focat.2019.12.004.
[8] Global solid oxide fuel cell market 2016-2026: integration technologies are providing growth opportunities. Focus Catal 2019;2019:2. doi:10.1016/j.focat.2019.04.009.
[9] Energy C, Group S. Europe solid oxide fuel cells market, competition forecast and opportunities report, 2013-2023 featuring LG Fuel Cell Systems, Fuel Cell Energy, SOLIDpower Group & Hexis AG. Focus Catal 2019;2019:2–3. doi:10.1016/j.focat.2019.02.010.
[10] Global direct methanol fuel cells market will reach US$367 M by 2025: Zion Market Research. Focus Catal 2019;2019:3. doi:10.1016/j.focat.2019.05.011.
[11] Zion Market Research. Zion Market Research, 2019. n.d, http://www.globenewswire.com
[12] IEA - International Energy Agency. Technology Roadmap Hydrogen and Fuel Cells. 2019.
[13] The Future of Hydrogen. 2019. doi:10.1787/1e0514c4-en.
[14] Sdanghi G, Maranzana G, Celzard A, Fierro V. Review of the current technologies and performances of hydrogen compression for stationary and automotive applications. Renew Sustain Energy Rev 2019. doi:10.1016/j.rser.2018.11.028.
[15] Felseghi RA, Carcadea E, Raboaca MS, Trufin CN, Filote C. Hydrogen fuel cell technology for the sustainable future of stationary applications. Energies 2019;12. doi:10.3390/en12234593.
[16] Nielsen ER, Prag CB. Learning points from demonstration of 1000 fuel cell based micro-CHP units 2017:38.
[17] FUEL CELLS and HYDROGEN 2 JOINT UNDERTAKING. PACE Pathway to a Competitive European Fuel Cell micro CHP Market Programme Review Days 2018. 2018.

[18] Disclosure TFS, Certification DBEC, Form U, Contractor P, Application P, Express B, et al. KfW 433 programme. vol. 21. 2020.
[19] Brennstoffzellen A. Brennstoffzellen Branchenführer Deutschland 2018 Fuel Cell Industry Guide Germany 2018. 2018.
[20] Energie V. Brennstoffzelle : Strom und Wärme maximal effizient n.d.
[21] FUEL CELLS and HYDROGEN 2 JOINT UNDERTAKING. Multi - Annual Work Plan. 2018.
[22] He HE, Pack S, Roadmaps T, Pack S. Hydrogen Europe - TECHNOLOGY ROADMAPS FULL PACK. 2018.
[23] Japan Hydrogen & Fuel Cell Demonstration Project Home Page n.d. http://www.jhfc.jp/e/index.html (toegang verkry 02 Januarie 2019).
[24] Weidner E, Cebolla Ortiz R, Davies J. Global deployment of large capacity stationary fuel cells – Drivers of, and barriers to, stationary fuel cell deployment. 2019. doi:10.2760/372263, JRC115923.
[25] Hydrogen Europe. Hydrogen Europe - Strategic Research & Innovation Agenda. 2019.
[26] Fuel Cell Today, Carter D, Wing J. The Fuel Cell Industry Review 2019. 2019.
[27] Hydrogen Council. Path to hydrogen competitiveness A cost perspective 2020.
[28] Tractebel E, Engie, Hinicio. Study on Early Business Cases for H2 in Energy Storage and More Broadly Power To H2 Applications. EU Comm 2017:228.