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Non-technical barriers for the SOFC adoption in the commercial sector and connected environmental and socio-economic impacts at the European scale

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Abstract:

The following document analyse the main non-technical barriers for the SOFC adoption in the EU area. The analysis relies on existing literature and FHC-JU projects focused on economic, legal and RC&S barriers. Finally, an update within the Comsos project has been performed in the Conclusions section.

Keyword list: SOFC systems, commercial sector, barriers, socio-economic impact, environmental impact

Summary

1. Introduction

The following document is focused on the non-technical barriers for the SOFC adoption in the commercial sector and connected environmental and socio-economic impacts at the European scale. The analysis is structured with a first summary of existing and known non-technical barriers for fuel cells at EU level, retrieved from the HyLaw and Ene.Field projects.

The second part is indeed associated with some economic considerations, especially linked with the strongly fluctuating energy prices of years 2021 and 2022. Finally, conclusions are drawn in terms of needs for regulations and supporting schemes, economic aspects and environmental and socio-economic benefits.

2. Fuel Cell Market status

The present section provides an update on the FC market status according to the 2022 Fuel Cell Industry Review [1], related to the installations in year 2021.

The year 2021 saw fewer stationary fuel cell units shipped than 2020, but more total power. This shows the slight shift in balance between very small units (e.g., Ene-Farm) and the bigger fuel cells put out by Doosan and Bloom. These different stationary fuel cells cover many stack types and can operate on conventional fuels, fuel mixes and synthetic fuels, white (by-product) and green (renewable) hydrogen.

In June 2021 Aisin Seiki and Toyota City in Aichi Prefecture announced a plan to encourage the take-up of the 'Type S' with City subsidies, and for the CO_2 savings to be tracked using IoT technology, to then be traded under a Japanese Government CO_2 credit scheme.

Korean corporations' interest in fuel cells reflects a joint Government/Industry ambition for 'green' technologies that reduce emissions, enhance energy security and can develop an indigenous industry capable of generating economic growth and exports. Strong Government drivers support these ambitions, which exceed those of most other countries. Reflecting its ambition, the Korean Government's Hydrogen Roadmap has a fuel cell target of 1.5 GW installed stationary capacity for power generation by 2022, reaching >8 GW by 2040, plus a further 7 GW of exports. The 2022 target will be missed, with the IPHE suggesting 688 MW installed capacity by the 2021 year-end – still very impressive. The forthcoming Clean Hydrogen Energy Portfolio Standard will provide specific support for fuel cell systems for power companies generating less than 500 MW.

The **US** was the first to deploy stationary FC systems at scale globally and for years had the world's largest fleet of 550-600 MW, only overtaken by Korea at the end of 2020. These are primarily commercial sized units of 100s of kW and low MW. Unlike Korea, large utility-scale deployments at tens of MW capacity have been the exception. This reflects the economics of power generation in the US, where self-generation has been encouraged by Federal and State regulations and incentives, and by individual corporate environmental policies.

Over the years, California's power and emissions challenges have driven State legislation in favour of alternative technologies, including fuel cells for DG. 2021 saw the State Government extend its Fuel Cell Net Energy Metering Program, providing relief from power utility charges to end users of FC systems. California is estimated to have around 550 stationary units totalling 320 MW, way ahead of any other State.

Connecticut, with a fleet of about 100 stationary units and an 84 MW installed base, is the only State to classify fuel cell systems as Class 1 Renewable Energy Sources, equivalent to PV and Wind, even when running on NG. Over the years the State, with an eye on growth and jobs, has enacted legislation requiring State power utilities to purchase home-grown technology. The Department of Energy & Environmental Protection (DEEP) initiative has sought bids for plants from renewable technology suppliers, including FC systems. The latest legislation, passed in Summer 2021, requires the State's utilities to solicit 30 MW of systems from fuel cell companies, which include Doosan and FuelCell Energy.

Ambition amongst **Europe**'s developers is not lacking, nor is technical competence. But the energy markets are tougher, the grid more reliable, Government subsidy regimes far less generous and regulations less favourable than in some other economies.

The PACE project aimed to install thousands of small scale SOFC systems in EU [2]. To date, most units have been deployed in Germany and in Flanders in Belgium. Both countries have national or regional subsidies adding to the PACE incentives. The only consistent government support available, at least at reasonable scale, has been KfW 433 in Germany. Since 2016, it is reported to have supported over 18,300 units (the initial target was 15,000 systems), of between 250 W and 5 kW, through a mix of grants and tariffs now worth up to €34,300 (US$40,800) a unit.

3. HyLaw project

HyLaw stands for Hydrogen Law and removal of legal barriers to the deployment of fuel cells and hydrogen applications. It is a flagship project aimed at boosting the market uptake of hydrogen and fuel cell technologies providing market developers with a clear view of the applicable regulations whilst calling the attention of policy makers on legal barriers to be removed. HyLaw main outputs have been:

- An online and publicly available database compiling legal and administrative processes applicable to hydrogen and fuel cell technologies in 18 countries across Europe
- National policy papers describing each legal and administrative process, highlighting best practices, legal barriers and providing policy recommendations
- A pan-European policy paper targeted towards European decision makers

- National and European workshops for dissemination of the findings and convincing public authorities to remove barriers

HyLaw started in January 2017 and run until December 2018. The main outcomes of the project are summarized below [3,4].

- Despite the undeniable advantages of the FC micro-CHP systems (high energy efficiency, smart grid capability) their presence on the market is limited so far. Supportive policies and appropriate framework conditions can accelerate the transition of the FC micro-CHP sector from emerging technology to full-scale commercialisation.
- The fuel cell micro-CHP systems have to be recognised as one of the key technologies capable to deliver greenhouse gas emission reductions, energy savings, integration of renewable energy sources and smart grid solutions.
- Simplified grid connection procedures and guaranteed access to the grid for electricity produced from high-efficiency micro-CHP systems, as well as supportive measures for the produced electricity can further contribute to overcome the roll-out phase.
- In addition, the FC micro CHP systems have to be accepted as an eligible technology in the national public procurement rules for purchase of products with high-efficiency performance in the government buildings. The public sector constitutes an important driver to stimulate market transformation towards high-efficiency technologies. Buildings owned by public bodies account for a considerable share of the building stock and have high visibility in public life.

The main recommendations, in 2018 at the project end, have been:

- Development and adoption of policies and concrete measures, recognising the energy efficiency and the smart grid functionality of the residential stationary fuel cells and promoting them as high-efficiency micro-cogenerations.
- Recognition of residential stationary fuel cells as an eligible technology under the Energy savings obligations according to Energy Efficiency Directive.
- Inclusion of the FC micro- CHP systems as high-efficiency technology in national strategies and public procurement rules for decarbonisation of the building stock.
- Provision of guaranteed access to the grid, guaranteed transmission and distribution and priority dispatch of the electricity produced from high-efficiency FC micro-CHP systems and creation of support mechanisms for the uptake of this electricity

Furthermore, specific recommendations where available for selected countries, and the main outcomes at national level are summarized below [5].

Italy

Recommendations:

- Implement at national level the Energy Efficiency Directive (EED) in order to realize the potential of fuel cell micro-CHP. Clarifying eligibility of micro-CHP, along with other energy saving end user technologies, as part of the Energy Savings Obligation, defined under Article 7 of the Energy Efficiency Directive, would ensure recognition of fuel cell micro-CHP benefits.
- Simplify grid connection procedures, both for gas and electricity grid, for fuel cell micro-CHP.
- Promote dedicated support mechanisms for fuel cell micro-CHP to foster the deployment of several units throughout Italy.
- Implement at national level a clean air directive to reduce the impact of conventional boilers and heating systems on the quality of the air. The directive should set very strong limitations in terms of emissions of SOx, NOx, CO, particulates and of other species armful for the environment and for the health.

4. Ene.Field project

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 the framework of the Ene.Field project [6]. 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 [7].

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 [7].

Potential risks for FC micro-CHP deployment in the medium to long term, linked to EU level legislation, include [6,7]:

- 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

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 [7,8].

5. Barriers to commercialization for stationary SOFC systems

According to the 2015 report "Advancing Europe's energy systems: Stationary fuel cells in distributed generation" [9], the main obstacles to the commercialisation of stationary FCs, as shown in Figure 1, are:

- High costs are the greatest obstacle to commercialisation
- Technical challenges persist, particularly regarding stack durability and reliability
- Lacking standardisation creates challenges in the supply chain
- Lack of awareness amongst the general public of stationary fuel cells
- Policy commitment to the fuel cell is insufficient

Furthermore, minor barriers have also been listed, as shown in Figure 2.

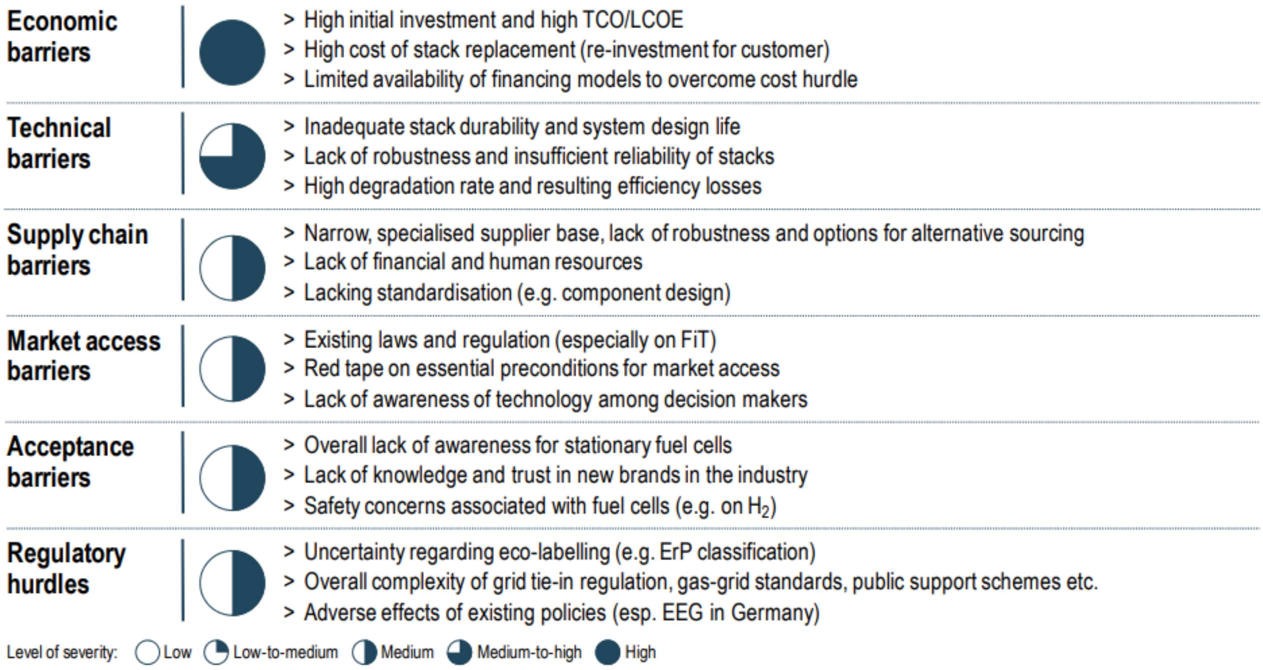

Figure 1. Major barriers to commercialisation for stationary fuel cells and their severity. [9]

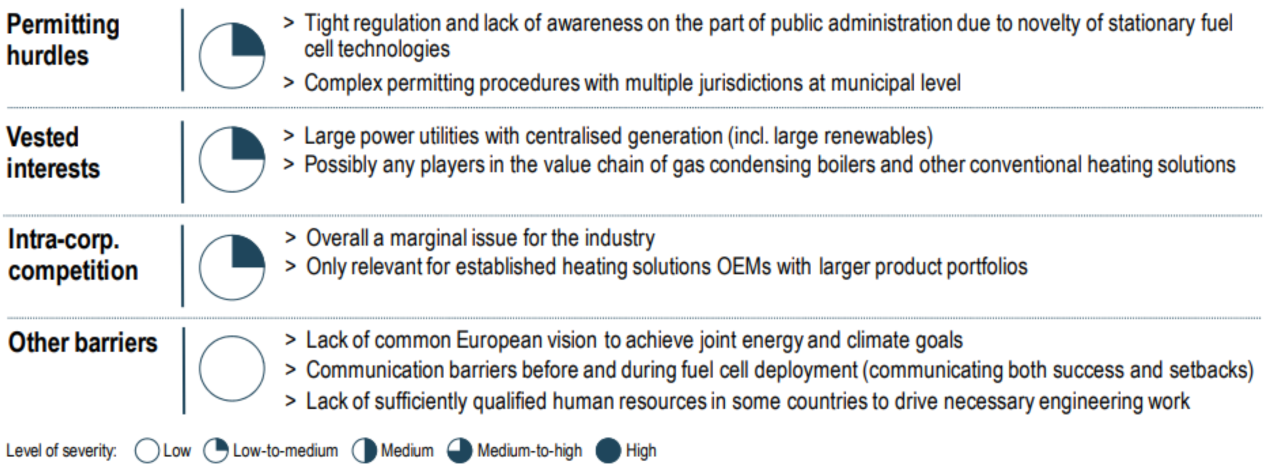

Figure 2. Minor barriers to commercialisation for stationary fuel cells and their severity. [9]

The high investment cost for SOFC is mainly linked with the currently low production volumes. An increase in the annual production rate up to 100 units (50 kW each) would generate a reduction in the SOFC manufacturing cost of 50%, as shown in Figure 3. Furthermore, the cost of an SOFC modules is strongly dominated by the stack CAPEX, which is the component expected to show the largest reduction with the increasing volumes. Anyway, as demonstrated for the biogas section in the work of Oluleye et al. [10] in the framework of the DEMOSOFC EU project [11], the current economic condition in Europe could lead to some installations (in countries with available supporting schemes on biogas or cogeneration) but these installations will not be enough for the SOFC systems to reach the pure market competitiveness, and dedicated funding schemes will be required.

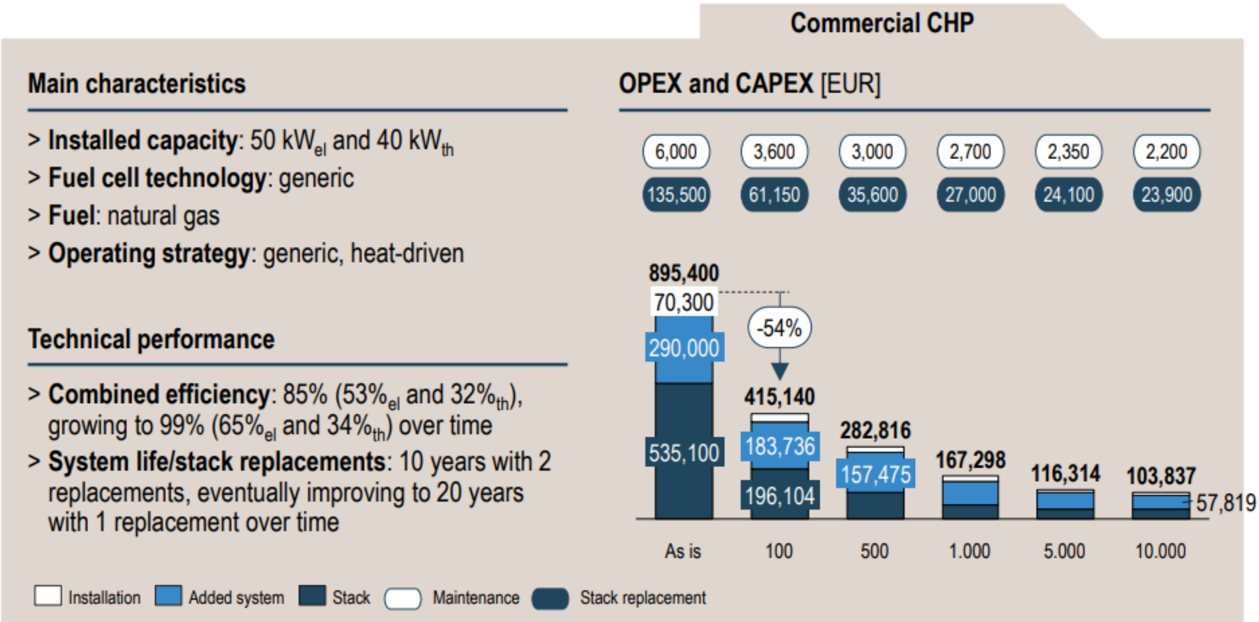

Figure 3. Technology and cost profile of a generic commercial 50 kW SOFC-CHP system. [9]

6. National policies

According to the 2021 Global Hydrogen Review of the IEA [14], in 2019 few countries were active for what concerning hydrogen-dedicated regulations. Japan and Korea had published national hydrogen strategies to define the role of hydrogen in their energy systems, and France had announced a hydrogen deployment plan. Since then and up to 2021, 13 countries (Australia, Canada, Chile, the Czech Republic, France, Germany, Hungary, the Netherlands, Norway, Portugal, Russia, Spain and the United Kingdom) have published hydrogen strategies, along with the European Commission. Colombia announced the release of its strategy for the end of September 2021. Two countries (Italy and Poland) have released their strategies for public consultation and more than 20 others are actively developing them. Several regional governments have also defined hydrogen strategies and roadmaps.

Buildings Electricity Exports Industry Industry (chemicals) Industry (steel) Mining Refining
Shipping Transport. Aviation

Country	Document, year	Deployment targets (2030)	Production	Uses	Public investment committed
Australia	National Hydrogen Strategy, 2019	None specified	Coal with CCUS Electrolysis (renewable) Natural gas with CCUS		AUD 1.3 bln (~USD 0.9 bln)
Canada	Hydrogen Strategy for Canada, 2020	Total use: 4 Mt H_2/y 6.2% TFEC	Biomass By-product H_2 Electrolysis Natural gas with CCUS Oil with CCUS		CAD 25 mln by 2026(1) (~USD 19 mln)
Chile	National Green Hydrogen Strategy, 2020	25 GW electrolysis(2)	Electrolysis (renewable)		USD 50 mln for 2021
Czech Republic	Hydrogen Strategy, 2021	Low-carbon demand: 97 kt H_2/yr	Electrolysis		n.a.
European Union	EU Hydrogen Strategy, 2020	40 GW electrolysis	Electrolysis (renewable) Transitional role of natural gas with CCUS		EUR 3.77 bln by 2030 (~USD 4.3 bln)
France	Hydrogen Deployment Plan, 2018 National Strategy for Decarbonised Hydrogen Development, 2020	6.5 GW electrolysis 20-40% industrial H_2 decarbonised (3) 20 000-50 000 FC LDVs (3) 800-2 000 FC HDVs (3) 400-1 000 HRSs (3)	Electrolysis		EUR 7.2 bln by 2030 (~USD 8.2 bln)
Germany	National Hydrogen Strategy, 2020	5 GW electrolysis	Electrolysis (renewable)		EUR 9 bln by 2030 (~USD 10.3 bln)
Hungary	National Hydrogen Strategy, 2021	Production: 20 kt/yr of low-carbon H_2 16 kt/yr of carbon-free H_2 240 MW electrolysis Use: 34 kt/yr of low-carbon H_2 4 800 FCEVs 20 HRSs	Electrolysis Fossil fuels with CCUS		n.a.
Japan	Strategic Roadmap for Hydrogen and Fuel Cells, 2019 Green Growth Strategy, 2020, 2021 (revised)	Total use: 3 Mt H_2/yr Supply: 420 kt low-carbon H_2 800 000 FCEVs 1 200 FC buses 10 000 FC forklifts 900 HRSs 3 Mt NH_3 fuel demand(4)	Electrolysis Fossil fuels with CCUS		JPY 699.6 bln by 2030 (~USD 6.5 bln)
Korea	Hydrogen Economy Roadmap, 2019	Total use: 1.94 Mt H_2/yr 2.9 million FC cars (plus 3.3 million exported)(5) 1 200 HRSs(5) 80 000 FC taxis(5) 40 000 FC buses(5) 30 000 FC trucks(5) 8 GW stationary FCs (plus 7 GW exported)(5) 2.1 GW of micro-cogeneration FCs(5)	By-product H_2 Electrolysis Natural gas with CCUS		KRW 2.6 tln in 2020 (~USD 2.2 bln)
Netherlands	National Climate Agreement, 2019 Government Strategy on Hydrogen, 2020	3-4 GW electrolysis 300 000 FC cars 3 000 FC HDVs (6)	Electrolysis (renewables) Natural gas with CCUS		EUR 70 mln/yr (~USD 80 mln/yr)
Norway	Government Hydrogen Strategy, 2020 Hydrogen Roadmap, 2021	n.a.(7)	Electrolysis (renewables) Natural gas with CCUS		NOK 200 mln for 2021 (~USD 21 mln)
Portugal	National Hydrogen Strategy, 2020	2-2.5 GW electrolysis 1.5-2% TFEC 1-5% TFEC in road transport 2-5% TFEC in industry 10-15 vol% H_2 in gas grid 3-5% TFEC in maritime transport 50-100 HRS	Electrolysis (renewables)		EUR 900 mln by 2030 (~USD 1.0 bln)
Russia	Hydrogen roadmap 2020	Exports: 2 Mt H_2	Electrolysis Natural gas with CCUS		n.a.
Spain	National Hydrogen Roadmap, 2020	4 GW electrolysis 25% industrial H_2 decarbonised 5 000-7 500 FC LDVs-HDVs 150-200 FC buses 100-150 HRSs	Electrolysis (renewables)		EUR 1.6 bln (~USD 1.8 bln)
United Kingdom	UK Hydrogen Strategy, 2021	5 GW low-carbon production capacity	Natural gas with CCUS Electrolysis		GBP 1 bln (~USD 1.3 bln)

Note: TFEC = total final energy consumption. (1) In addition to CAD 25 mln, Canada has committed over CAD 10 bln to support clean energy technologies, including H_2. (2) This target refers to projects that at least have funding committed, not to capacity installed by 2030. (3) Target for 2028. (4) From the interim Ammonia Roadmap. (5) Target for 2040. (6) Target for 2025 from the National Climate Agreement, 2019 (currently under revision). (7) Norway's strategy defines targets for the competitiveness of hydrogen technologies and project deployment.

Figure 4. Governments with adopted national hydrogen strategies; announced targets; priorities for hydrogen and use; and committed funding [14].

For what concerning the investments in FCH, hydrogen has proven remarkably resilient during the economic slowdown induced by the global pandemic. Companies specialised in producing, distributing and using hydrogen raised almost USD 11 billion in equity between January 2019 and mid-2021 – a considerable increase from prior years – and contracts funded by government recovery packages are expected to raise project investments substantially [14]. Nevertheless, funding is grossly insufficient to accelerate innovation to the level required to realise hydrogen's 60 Gt of CO_2 emissions reduction potential modelled in the Net zero Emissions Scenario.

7. Discussion

In the last years, because of the COVID pandemic and the Ukraine war, energy prices have shown a high volatility with a continuous increasing trend, as shown in Figure 4 for the natural gas and in Figure 5 and Figure 6 for electricity (in Italy and Germany respectively).

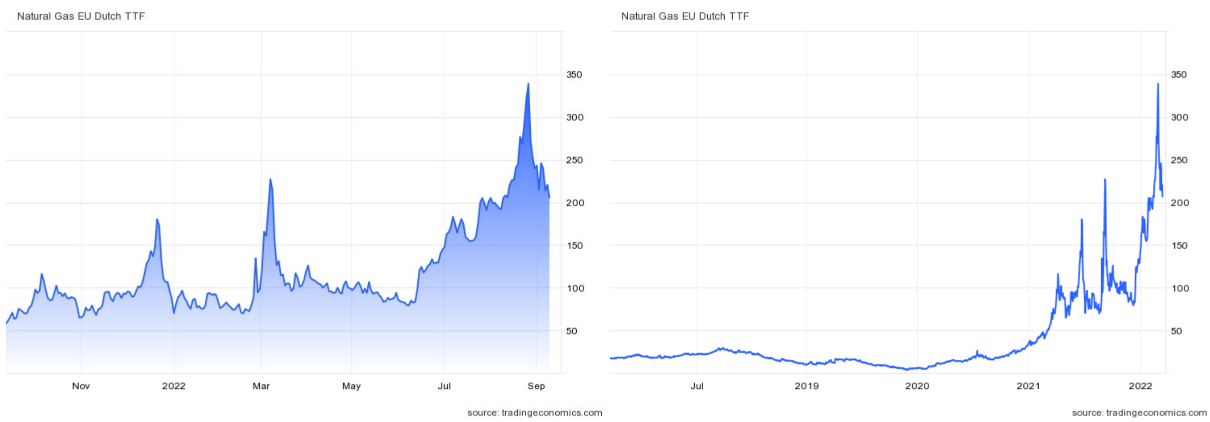

Figure 5. Natural gas EU price during Sep 2021-Sep 2022 (left) and last 5 years (right). [12]

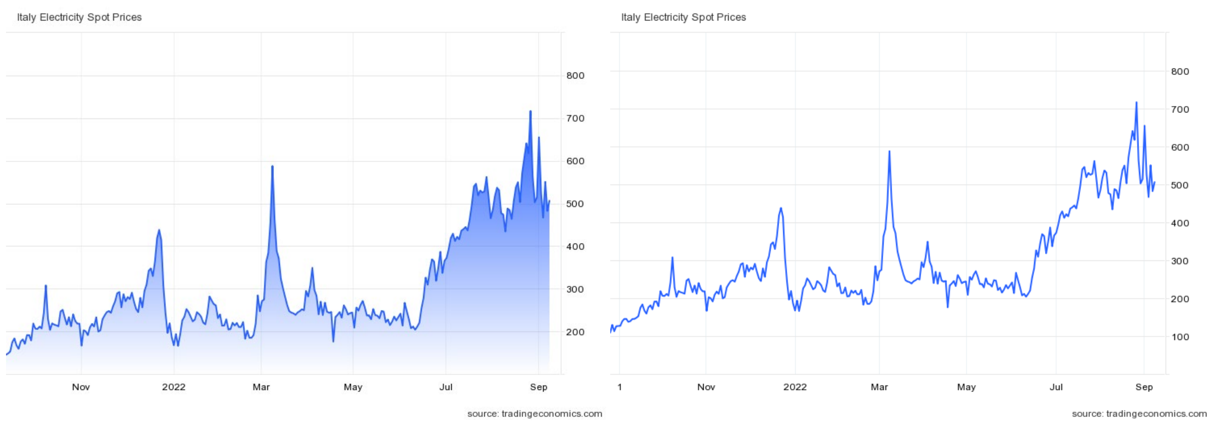

Figure 6. Electricity price in Italy during Sep 2021-Sep 2022 (left) and last 5 years (right).

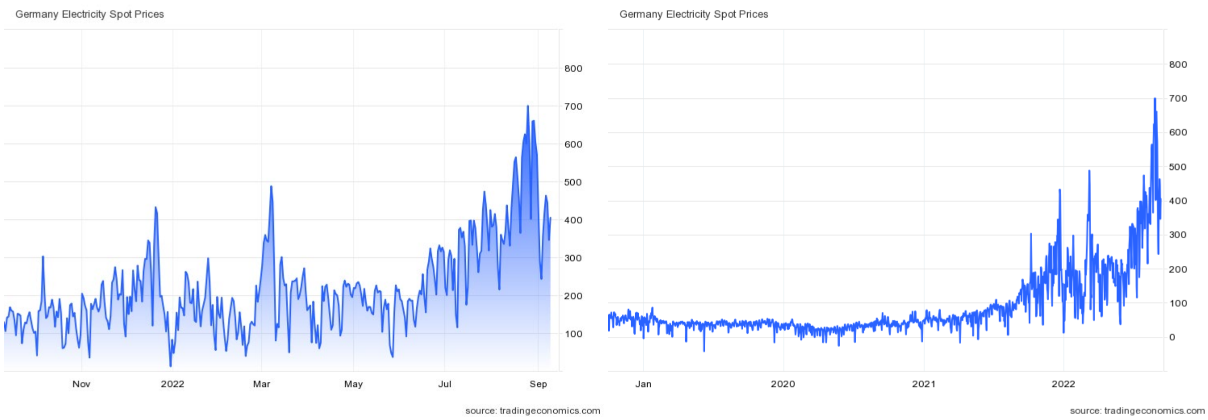

Figure 7. Electricity price in Germany during Sep 2021-Sep 2022 (left) and last 5 years (right). [12]

The SOFC-CHP market has been mainly focused on the natural gas fuel feeding in the last decades. The market introduction of a system fed by a fossil and very expensive fuel like natural gas, has brought to a decreasing interest in the technology from this perspective. The SOFC convenience is in fact possible only in countries where the natural gas price is lower than the electrical one, as shown in the work from Marocco et al. [13] and as reported in Figure 7. Figure 8 also shows that high influence, as reported in the report discussed in the previous chapter, of the stack lifetime and system efficiency.

Despite the critical aspect linked with natural gas feeding, SOFCs can work with multiple fuels increasing hydrogen and decarbonized methane (biological and synthetical) and can produce electric power with a best-in-class efficiency and zero pollutants emissions to the atmosphere (NOx, SOx, PM). These advantages, and the possibility of feeding the system with decarbonized fuels, give new opportunities to the SOFC products, which could be competitive with electrification in special context (e.g., commercial building with a constant base load and thermal needs).

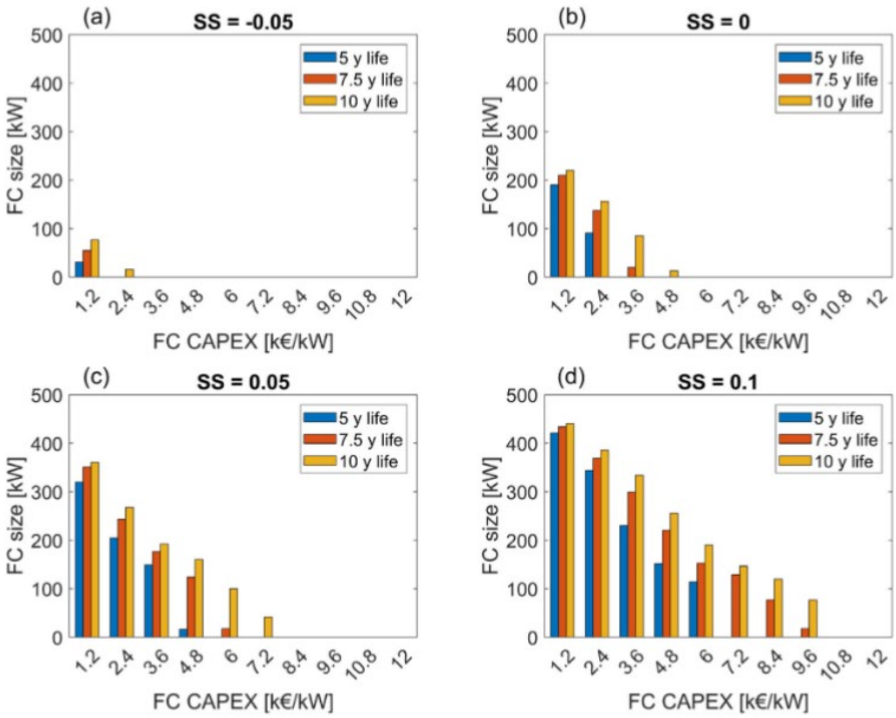

Figure 8. FC size as a function of the FC CAPEX for different FC stack lifetime values and spark spread values: SS=−0.05 (a), SS=0 (b), SS=0.05 (c), and SS=0.1 €/kWh (d). The current FC efficiency curve is considered. [13]

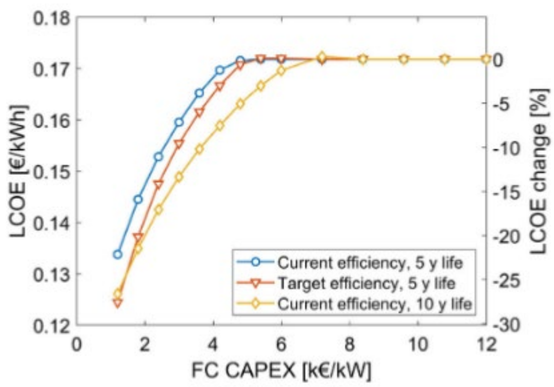

Figure 9. LCOE as a function of the FC CAPEX for different spark spread values. The graphs refer to the current FC efficiency curve and FC stack lifetime of 5 years. The secondary-axis shows the percentage change in LCOE with respect to the case with current FC CAPEX. [13]

Summarizing, the main non-technical barriers for the SOFC adoption are:

- Lack of dedicated subsidies and regulations/normative for the FCH technologies. Clean Hydrogen initiative is providing funding at EU level, but national policies should be available for replication of successful solutions previously demonstrated.

- High investment cost for the SOFC technology. This term includes the SOFC module initial investment, the stack replacement, and the onsite maintenance service.
- Volatility of energy prices (especially natural gas cost).
- The technology should undergo a switch from fossil to renewable fuels (e.g., hydrogen, biomethane) feeding to compete with the electrification of the building sector. Even if natural gas has been also included in the EU taxonomy during 2022, and even if its environmental emissions could represent a "cleaner" solution compared to other alternatives in the short-term energy transition, the use of fossil-based fuels has shown a reducing interest in the last years and this should be considered for the future of FC-based systems, especially in regions where electricity is available when a high share of renewables in the mix.

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