TECHNOLOGY READINESS LEVEL (TRL) - 2023

TECHNOLOGY DETAILS

Technology: **Solid Oxide Fuel Cell (SOFC)**
Sub-technology: **High-Temperature Fuel Cell**

Value chain: Generation
Sub-sector or technology: Hydrogen, Power
Sector: Energy transformation
Demand/Supply/Infrastructure: Supply

TRL $_{2023}$: 9

According to IEA criteria, the TRL of this technology in 2022 was: **7-9**
Several industries have now deployed SOFC commercial units in relevant environment. Many European nations are constructing large-scale stationary fuel cell projects for electricity production, with a concentration on the industrial and commercial sectors. For instance, in Italy, starting in 2022, Ferrari is building, at its Maranello facility, a new 1 MW solid oxide fuel cell unit to power the industrial complex. Only in the European ene.field program, 403 SOFC micro-CHP units have been installed, while in Japan about 136000 units.

TECHNOLOGY DESCRIPTION

Fuel cells are a further option to convert hydrogen into electricity and heat, producing only water and no direct emissions. Fuel cells can achieve high electric efficiencies of over 60% (above 80% overall efficiency when also including the heat output) and reveal a higher efficiency in part load than full load, which makes them particularly attractive for flexible operations such as load balancing. Molten carbonate fuel cells (MCFCs) and solid oxide fuel cells (SOFCs) operate with 600°C and 800-1 000°C, respectively, at higher temperatures, which allows them to run on different hydrocarbon fuels, without the need for an external reformer to produce hydrogen first. MCFCs are used in the MW scale for power generation (due to their low power density, resulting in a relatively large size).

In general, these fuel cells offer a versatile and adaptable choice for producing huge amounts of power, with applications in a range of settings and industries. Overall, factors like rising demand for clean energy, supportive governmental policies, and the development of hydrogen infrastructure are projected to spur further growth in the market for large-scale fuel cell applications in the coming years. The following industries can be approached:

- Fuel cells may be used in microgrids to provide stable, dependable, and resilient electricity to communities, particularly in rural or off-grid areas.

- Distributed power generation, which locates small power plants close to the location of consumption. For instance, in the United States, FuelCell Energy has installed several MWs of fuel cell capacity for distributed power production, including at colleges, military sites, and wastewater treatment facilities.

- Fuel cells can also be used in combined heat and power (CHP) systems, which use the leftover heat from the generation of electricity to provide heating or cooling. CHP systems may be very efficient and cost-effective in buildings with large energy needs, such as hospitals or colleges.

KEY COUNTRIES

U.S.; Germany; France; U.K.; China; Japan; South Korea

PROTOTYPE OR DEMONSTRATION PLANS, DEDICATED INVESTMENTS, LEADING INITIATIVES

Capacity additions in 2020 (largely natural gas fired fuel cell systems): 150 MW globally.

Companies: Bloom Energy, Sunfire Fuel Cells, Elcogen, SolidPower, Bosch, Ceres, Wärtsilä/Convion, Viessmann, SOFCMAN, CNFC, Toshiba, Doosan.

The United States is a pioneer in the use of sustainable energy in industries including transportation and electricity generation. This is explained by the fact that sustainable energy options now have more significance because to the U.S. government's energy act. France and the United Kingdom are two European nations making significant investments in the research and development of solid oxide fuel cells for use in power generation. In 2022, Asia Pacific led the world market and had a revenue share of nearly 49.48% (https://www.grandviewresearch.com/industry-analysis/solid-oxide-fuel-cells-market). In North America, stationary markets account for the majority of wide-scale applications for solid oxide fuel cells. Over the projection period, the market is anticipated to experience the greatest growth rate. Due to strong government support and a strategic market focus, the solid oxide fuel cell (SOFC) market in the United States has expanded at an incredible rate and is rising significantly relative to the rest of the world. The majority of the US market uses SOFC (300 MW installed), with subsidies ranging from 600 to 1200 EUR/kW (NG or Biogas) and a price per sale of 10,000 USD/kW. There are 1.8 MWs of SOFC systems in Europe. One of the major markets in Europe for SOFC applications is Germany. This can be ascribed to the German government's well-organized energy programs and specific goals.

COST REDUCTION TARGETS

State-of-the-art costs and future cost targets of the FCH 2 JU for large-scale fuel cells systems (0.4-30 MW) for converting hydrogen or renewable methane into electricity:

2017: USD 3 390-3 955/kW
2020: USD 2 260-3 390/kW
2024: USD 1 695-2 825/kW
2030: USD 1 356-1 977/kW

For smaller installations, the SOFC BOP cost share is largest (44.6–56.5%), but for larger installations, between 10 and 25 kW, the CHP hardware components have the highest rate. The fuel processing-related costs for SOFC systems were much lower because of their higher temperatures and fuel flexibility. They also benefited from the internal reforming process that occurs naturally in SOFCs, which eliminated the need for an external, overly-designed reformer.

The SOFC program has the following specific objectives: to achieve an efficiency of greater than 60% without carbon capture and storage; to meet a stack cost target of $225/kW and a system cost target of $900/kW; to demonstrate lifetime performance degradation of less than 0.2% per 1,000 hours over an operating lifetime of 40,000 hours (Report on the Status of the Solid Oxide Fuel Cell Program, Report to Congress, August 2019, US DOE).

Various organizations are working on SOFC/SOEC technology throughout Europe, with some assistance from the FCH JU. Around 218 million euros have so far been granted to 58 projects that focus on SOFC or SOEC technology. 40–50% of the funding given to energy-related projects is allocated to Solid Oxide technology projects.

(Mirela Atanasiu et al 2021 Meet. Abstr. MA2021-03 5). In the SRIA Key Performance Indicators (KPIs), the Clean Hydrogen JU projects a cost reduction of 10,000 €/kW to 3,500 €/kW for applications with less than 5 kW of installed power, 2,500 €/kW for applications with 5–50 kW of installed power, and 2,000 €/kW for applications with 50–500 kW of installed power by the year 2030.

DEPLOYMENT TARGETS

Korea:

- 1.5 GW by 2022 and 8 GW (and 7 GW more for exports) by 2040 for district grid systems (1-30 MW)
- 50 MW by 2020 for small to medium systems (up to 400 kW)

United States (USA):

A commercial organization is actively sought after by the DOE Program to collaborate on the design, production, testing, and commercialization of a 1–10 MW SOFC power system. Systems with this capacity represent a significant improvement over existing concepts. Ten 100 kW modules may, however, be combined to create a 1 MW system, which is now possible.

Europe:

Aiming to install more than 2.5 GWe of stationary fuel cells by 2030, the Strategic Research and Innovation Agenda of the Industry and Research (SRIA-HE/HER) set this as its lofty goal.

RELEVANT PARAMETERS

Temperature (ºC)	600 – 1,000
Efficiency (kWh/kg)	11 (small stack - 5 kW, fueled with CH4), up to 18
System cost (€/MW)	10,000 €/kW
Cell lifetime (h)	40,000 (DOE) - 80,000
Temperature resistance materials	600 – 1,000

Based on expert input:

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