Carnegie Mellon University
Wilton E. Scott Institute
for Energy Innovation

POLICY BRIEF

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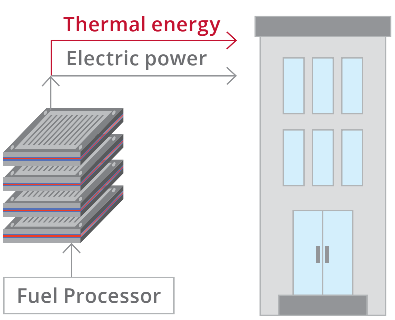
Solid Oxide Fuel Cells

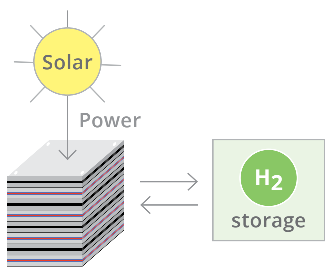
Advancing Solid Oxide Fuel Cell Technical and Economic Viability

SOLID OXIDE FUEL CELLS

Solid oxide fuel cells (SOFCs) are solid-state, high-temperature (typically greater than 600 °C), electrochemical devices that convert chemical energy from hydrogen or hydrocarbon fuels directly into electricity and thermal energy. Fuel and air react along electrode-electrolyte interfaces, producing electric current without the combustion or criteria pollutants of conventional technologies.



Fuel cells can be stacked for more power and integrated into a system to generate continuous, distributed, uninterruptible power for commercial, government and residential applications, as well as industrial processes.



SOFCs can operate on fossil or renewable fuels. A solid oxide electrolysis cell runs in the reverse direction of an SOFC to electrolyze water (H_2O) into hydrogen (H_2) and oxygen (O_2). A **solid oxide electrolyzer powered by solar**, for example, can produce hydrogen from water. SOFCs can also be hybridized with gas turbines to increase overall electric efficiency.

MEETING SYSTEM COST AND STACK DEGRADATION TARGETS

Findings from our expert interviews suggest that SOFC systems will meet the U.S. Department of Energy's (DOE's) system cost target of $900/kW$_{net}$ and stack voltage degradation rate target of 0.2%/1,000 hrs by 2035–2050.[2,3,*,†,‡]

2017
Cost = \$2,700/kW$_{net}$
Degradation = 1%/1,000 hrs

2020
Degradation rate could decline to 0.5%/1,000 hrs

2035
Cost = \$1,200/kW$_{net}$
Degradation = 0.3%/1,000 hrs
Targets almost met

2050
Cost = \$800/kW$_{net}$
Degradation = 0.2%/1,000 hrs
Targets met

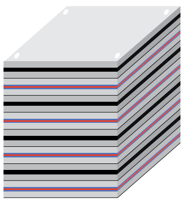
Benefits of SOFCs

- **Efficient:** High electric and combined heat and power system efficiencies reduce fuel consumption and carbon emissions
- **Reduced Carbon Emissions when Used with Renewables:** Carbon emissions can be further reduced using carbon capture and sequestration or by operating on hydrogen made from the renewable electrolysis of water or biofuels derived from biomass
- **Modular:** Power output can be scaled by stacking SOFCs without compromising efficiency
- **Fuel-Flexible:** Systems can operate on gaseous (natural gas, hydrogen, biogas and propane) and liquid (diesel, JP-8 and kerosene) fuels
- **Clean and Quiet:** Negligible criteria pollutants (NO_x, SO_x, CO and particulate matter) and volatile organic compounds,[1] plus quiet (few moving parts)

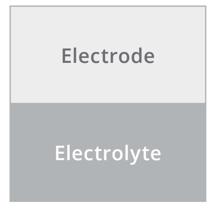
* *Cost is defined as the capital cost, expressed in dollars per net kilowatt. Degradation rate is the reduction in the stack's voltage, expressed as a percentage of the stack's beginning-of-life voltage, divided by the operating time elapsed.*

IMPROVING VIABILITY AND IDENTIFYING NEAR-TERM MARKETS

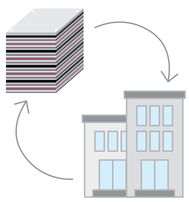
During our interviews[2] and workshop,[4] experts ranked barriers to advancing SOFC viability and identified potential near-term SOFC markets.



Stack Costs
Sixty-three percent of respondents identified the stack cost as the most considerable barrier to reducing system cost. Respondents identified materials and machinery (including operation) costs as the most considerable barriers to reducing stack cost.



Cell and Stack Degradation
Fifty-six percent of respondents identified chromium poisoning of the air electrode as the most considerable barrier to mitigating stack degradation. Experts also identified electrode chemical and microstructural changes and seal and separator plate degradation as considerable.



Need for Demonstrations
Thirteen percent of respondents identified the lack of demonstration and validation projects as the most considerable barrier to advancing SOFCs' widespread viability.

Entry-Level Markets
Forty-eight percent of respondents identified medium-scale (between 5 kW and 500 kW) and 35% of respondents identified small-scale (<5 kW) applications as the most favorable entry-level markets.

Summary

SOFCs could meet the U.S. DOE's cost and degradation rate targets by 2035–2050.

Our findings suggest that an increase in RD&D spending on cell, stack and systems development, particularly projects to reduce the system's capital cost and increase system deployments, could accelerate progress toward meeting goals.

Smaller applications (less than 500 kW) that generate primary power may be suitable entry-level markets that can help advance the widespread viability of fuel cells.

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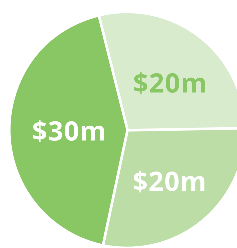
RECOMMENDED RD&D FUNDING

Experts recommended government funding in FY 2018 to meet the DOE's targets, assuming subsequent funding would remain at a similar level after FY 2018.[2,5,†,‡]

Systems Development
Integration, manufacturing and deployment of systems to facilitate market penetration



Core Technology
Reduction of cost and improvement of durability of stacks and system components

Cell Development
Improvement of fuel cell cost, performance and durability

† *Median values reported. Experts ranged in their assessments.*

‡ *All dollar amounts are expressed in 2017 USD, and all costs assume high-volume manufacturing.*

1 *U.S. Environmental Protection Agency. 2017. Catalog of CHP Technologies Available at: www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf.*

2 *Whiston, M.M., et al. 2019. Meeting Solid Oxide Fuel Cell Cost and Degradation Rate Targets. Manuscript submitted.*

3 *Vora, S.D. 2018. U.S. DOE Office of Fossil Energy Solid Oxide Fuel Cell Program. 19th Annual Solid Oxide Fuel Cell (SOFC) Project Review Meeting (Washington, D.C.). Available at: www.netl.doe.gov/sites/default/files/netl-file/FE0-SOFC-SOFC-Program-Overview-2018-AMR.pdf.*

4 *Whiston, M.M., et al. 2019. Workshop on Solid Oxide Fuel Cell Cost, Degradation, and Market Viability. Manuscript in preparation.*

5 *National Energy Technology Laboratory. Solid Oxide Fuel Cell. Available at: www.netl.doe.gov/coal/fuel-cells [Accessed April 10, 2019].*

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