Solid Oxide Fuel Cell R&D

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ABSTRACT

The mission of the Department of Energy's Office of Advanced Fossil Technologies Program is to advance technology development that increases the availability, performance, reliability, and efficiency of existing and a new power systems. The Advanced Energy Systems Division within this Program supports research and development of Solid Oxide Fuel Cells (SOFCs) to enable generation of efficient, cost effective electricity from such distributed generation systems in the near term, complete with stack and system development. In the near term (2020) this smaller, highly efficient and fuel flexible SOFC technology will exploit abundant natural gas resources with ability to use syn-gas from coal in the long-term (2030).

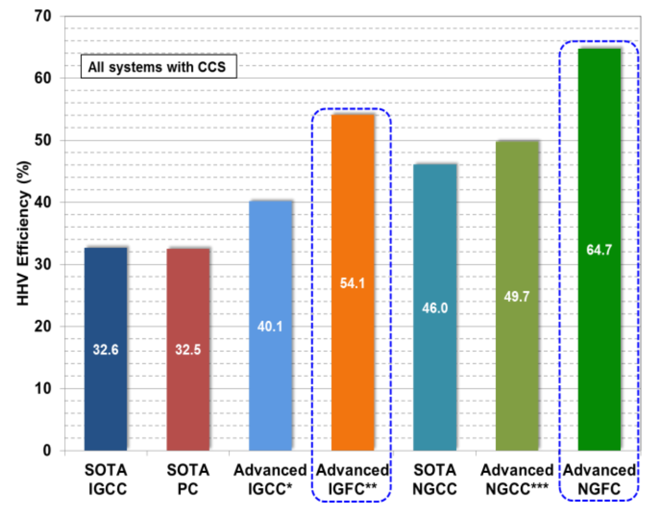
Keywords: solid oxide fuel cells, three key technologoies, cell degradation

1 INTRODUCTION

Solid oxide fuel cells (SOFCs) are well-suited to stationary applications because they are efficient (even at small scale), have low emissions, are scalable from a few kW to multi-MW, operate quietly, have low maintenance, and can use a broad gamut of fuels (various hydrocarbons, hydrogen). Solid oxide fuel cell technology is the most promising technology for smaller, modular-scale as well as large-scale power generation and have the potential to enable coal-based power plants to achieve efficiencies near 60% HHV of which techno-economic analysis of power plant has been done by NETL for both coal gas and natural gas (Figure 1) [1].

The U.S. Department of Energy through the National Energy Technology Laboratory (NETL), initiated the Solid State Energy Conversion Alliance (SECA) in 2000 to develop low-cost, environmentally friendly solid oxide fuel cell (SOFC) technology. Initially the SECA program focused on developing state-of-the-art materials for cells and stacks. Through DOE/NETL funding for research and development the SOFC Program has made a good progress and is poised for demonstrating commercially relevant and robust systems.

The specific goals of the SOFC program are: to meet a stack cost target of $225/kW and a system cost target of $900/kW; demonstrate lifetime performance degradation of less than 0.2% per 1,000 hours over an operating lifetime of 40,000 hours; and achieve an efficiency of greater than 60% without carbon capture and storage.



SOTA: State of the Art
IGCC: Integrated Gasification Combined Cycle
PC: Pulverized Coal
IGFC: Integrated Gasification Fuel Cell
NGCC: Natural Gas Combined Cycle
NGFC: Natural Gas Fuel Cell

Figure 1: Techno-Economic Analysis of Power Plant.

2 CHALLENGES

The challenges for SOFC are to reduce cost and increase reliability and performance. Those challenges cover from the cell, to interconnect and seal to the balance of plant (BOP). Despite all the work done to date, there are many barriers to overcome before the SOFC systems can move to commercialization. The challenges include, but not limited to:

- the performance of SOFC system which is not long enough for large scale commercial applications,
- the system level degradation rate which remains a 1 to 1.5 % per 1000 hours for long operation time;

- the overall cost of SOFC systems which is not competitive with conventional alternatives; and
- availability of the integrated testing of SOFC systems with balance of plant.

These challenges are being addressed by DOE SOFC program through funding of universities, national laboratories, and corporations that participate.

3 PROGRAM OVERVIEW

The objective of the SOFC program is to reduce the cost of components, stack, and balance of plant (BOP) to make this technology economically competitive while having a reliable performance and durability.

The DOE/NETL SOFC Program maintains a portfolio of RD&D projects that address the technical issues facing the commercialization of SOFC technology. To successfully complete the maturation of the SOFC technology from its present state to the point of commercial readiness, the Program's efforts are channeled through three key technologies, each of which has its respective research focus (Figure 2).

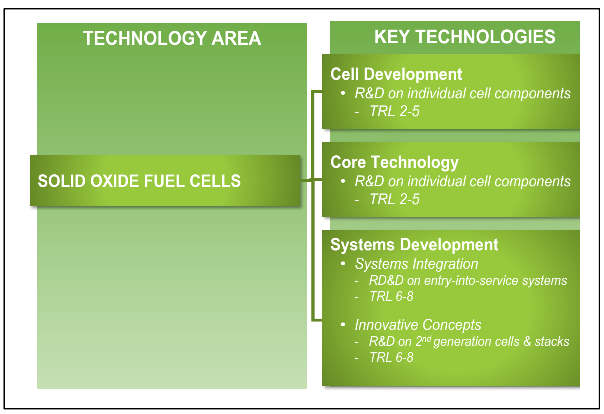


Figure 2: DOE/NETL SOFC R&D Focus Areas.

Cell Development program is focusing on improvement of cell performance, reduction of cell degradation and cost reduction of materials of cell and stack components. Core Technology program is focusing on addressing the key technology barriers of stack and BOP. The topic work under the Core Technology program is the improvement of cell performance, degradation and seals guided by the industrial teams. Innovative Concept supports the R&D of SOFC technology that has the potential to significantly surpass current SOFC technology in terms of cost, robustness, reliability and endurance through novel cell and stack concepts, advanced processing techniques and novel fuel cell power systems.

Chromia-forming common stainless steel for cost reduction of SOFC commercialization is preferred metallic interconnect and BOP component materials. However, chromium-containing volatile species forms on this steel surface at SOFC operation temperature, which is one of the main cathode degradation factors in SOFC power generation systems and contributes performance losses in long-term operations. PNNL has developed a chromium getter technology that can capture chromium to effectively mitigate the cathode poisoning before it reaches to the electrochemically active interface of the electrolyte and the cathode. The getter was tested with the cell degradation lower than, by 25 to 30%, that of the baseline condition which has no chromium capture technology [2].

The electrochemical kinetics of oxygen reduction at the cathode side is slower than that of hydrogen oxidation at the anode side. The major performance losses are ascribed to the cathode degradation caused by cathode materials degradation as well as chromium poisoning. In order to improve cell performance and long-term stability, NETL has developed a single-step solution infiltration where nano-sized catalytic materials are introduced into a cathode, resulting in improvement of state-of-the-art technology reliability at the cell level with 10% peak power increase and 33% reduction of degradation rate [3-5].

Through DOE/NETL funding, two Proof-of-Concept (POC) SOFC power systems were successfully demonstrated by FuelCell Energy (FCE) and LG Fuel Cell Systems (LGFCS), respectively. FCE built and tested a 50kW SOFC system at AC power 55% efficiency (HHV) with a degradation rate of 0.9%/1000 hours. LGFCS built and tested a pressurized SOFC system, delivering 200 kW of AC power at 57% efficiency (HHV).

Going forward to near-term focus, as the laboratory scale tests have been making progress successfully, prototype system test is focused on component scales for MW-level in the mid 2020 timeframe. The long-term focus of SOFC Program is on coal or natural gas fueled central power generation, with Transformational SOFC technology ready to be deployed at the commercial scale in the 2030-2040 time frame.

4 SOFC-CHP-HYBRID POWER SYSTEMS

The combined heat and power (CHP) based on SOFC is very attractive due to the high potential to operate at high overall system efficiency on natural gas, biogas and coal gas. The CHP can be integrated with an existing heating system such as in distributed and centralized power applications. For the residential/distributed application, the SOFC can be coupled with a water tank to generate not only heat of the space and water heating but also electricity. For the centralized application, the un-reacted fuel is sent to afterburner if the fuel utilization is high enough and heat from the exhaust gas of the afterburner is recovered to produce steam to drive the steam turbine cycle for generation of additional electrical energy. when the fuel utilization is lower than 80% [6], another way to recover thermal energy in the SOFC exhaust is to integrate the SOFC with a gas turbine cycle for an ultra-high efficiency (>70%) combined cycle configuration since the temperature of SOFC exhaust is high. NETL has done performance analysis of the fuel utilization effects on the SOFC in gas turbine hybrid systems [6], the maximum system efficiency is realized at the fuel utilization of 75% to 80%.

5 CONCLUSION

Since the SOFC Program inception in 2000, the program has made substantial progress, including a tenfold reduction in stack cost and a fivefold improvement in stack power density. The program has also made progress in overcoming the challenges involved in scaling up solid-oxide fuel cells, achieving a fivefold increase in cell area and a 25-fold increase in stack size. The research conducted so far has allowed the program to install a 400 kW system at a power company for base load using natural gas which should lead to a 1 MW system by 2020.

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