SOLID OXIDE FUEL CELL PROGRAM

OVERVIEW

The primary mission of the U.S. Department of Energy's (DOE) Office of Fossil Energy is to ensure the nation can continue to rely on its indigenous fossil fuel resources for clean, secure, and affordable energy. Contributing to that mission is the Solid Oxide Fuel Cell (SOFC) Program, administered by the Office of Fossil Energy's National Energy Technology Laboratory (NETL). The SOFC Program focuses on research, development, and demonstration (RD&D) to enable generation of highly efficient, cost-effective electricity from coal and natural gas with near-zero atmospheric emissions of carbon dioxide (CO_2) and criteria pollutants and minimal water consumption.

NETL

NATIONAL ENERGY TECHNOLOGY LABORATORY

OVERVIEW

DOE's SOFC program is conducted under the Clean Coal and Carbon Management Research Program (CCCMRP). Fossil fuels account for over 80 percent of total U.S. primary energy use due to their abundance, high energy density, and the relatively low costs associated with production, safe transport, and use. However, the combustion of fossil fuels to generate electricity is the largest single source of CO_2 emissions in the nation, accounting for one third of total U.S. CO_2 emissions. Control and mitigation of such greenhouse gases is a national focus. A primary goal of President Obama's Climate Action Plan is to "cut carbon pollution in America."

Ensuring that the nation can continue to rely on clean, affordable energy from ample domestic fossil fuel resources is the principal mission of DOE Office of Fossil Energy research programs. As a component of that effort, the CCCMRP—administered by the Office of Fossil Energy and implemented by NETL—is engaged in RD&D activities with a goal to develop and deploy innovative energy technologies and inform data-driven policies that enhance U.S. economic growth, energy security, and environmental quality.

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THE PROGRAM

The SOFC program supports the mission and goals of the CCCMRP through the development of low-cost SOFC power generation systems that produce electric power from coal or natural gas with intrinsic carbon capture capabilities. SOFC power systems have the potential to achieve greater than 60 percent efficiency and more than 97 percent carbon capture at a cost-of-electricity projected to be 40 percent below presently available integrated gasification combined cycle systems (IGCC) equipped with carbon capture. The SOFC's operating temperature (less than 1650 °F) is lower than combustion-based processes and precludes NO_X formation; there are near-zero emissions of CO_2, criteria pollutants, and particulates. Furthermore, SOFC power systems require approximately one-third the amount of water relative to conventional combustion-based power systems.

The SOFC Program is committed to developing efficient, low-cost electricity from natural gas or coal with carbon capture capabilities for distributed generation (DG) and central power generation applications; maintaining cell development and core technology research to increase the reliability, robustness, and durability of cell, stack, and system technology; and providing the technology base to permit cost-competitive DG applications and utility-scale systems with carbon capture capabilities.

SOFC technology is inherently modular and fuel flexible. Thus cell and stack designs demonstrated at the bench scale can directly be scaled and aggregated into modules that serve as the building blocks for utility-scale SOFC power systems.

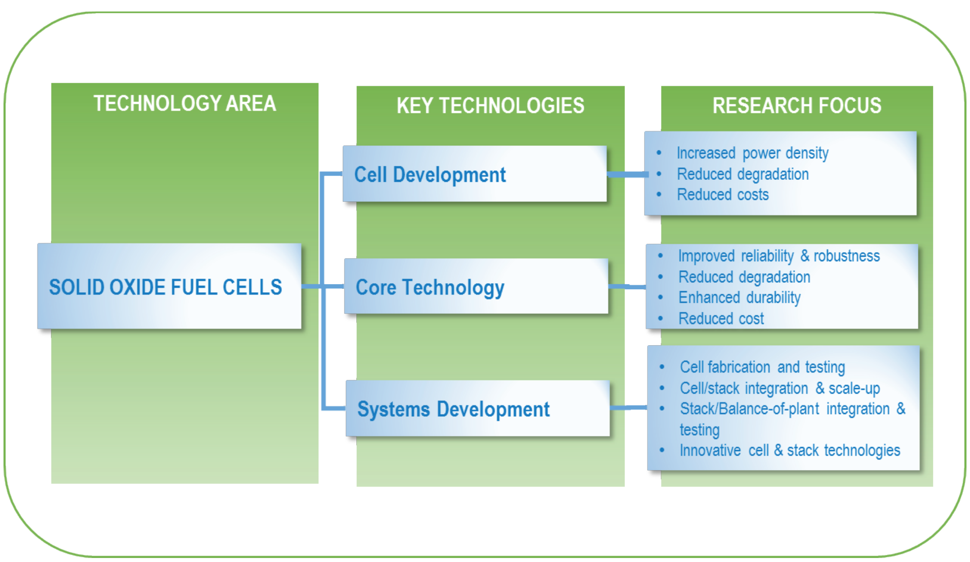
The SOFC's ability to internally reform methane allows for a common module design for use with either natural gas or coal-derived synthesis gas (syngas). Capitalizing on these inherent capabilities, an attractive pathway to the deployment of central station SOFC systems (fueled by either natural gas or syngas) is through the development of natural-gas-fueled DG SOFC power systems.

A natural-gas-fueled DG SOFC system will employ essentially the same cell and module technology as that intended for use with syngas. Because the DG system will be smaller in size and have a simpler front-end fuel supply, it will most likely be first to the marketplace. Its development is synergistic with the development of syngas-fueled utility-scale applications. Thus, the performance, reliability, and durability targets and cost reductions pursued by the SOFC program for utility-scale applications are closely aligned with the near-term DG goals of industry—without compromising the goals of the coal-based program.

KEY TECHNOLOGIES

The SOFC Program consists of three key technologies: (1) Cell Development, (2) Core Technology, and (3) Systems Development (Figure 1).

Cell Technology—The electrochemical performance, durability, and reliability of the solid oxide fuel cell are the key determinants in establishing the technical and economic viability of SOFC power systems. The components of the



SOFC—the anode, electrolyte, and cathode—are the primary research emphasis of Cell Technology. Based on feedback from SOFC developers, who identified chromium contamination as a major contributor to cell degradation and reduced reliability, NETL launched an initiative to address and mitigate chromium poisoning. Additional research efforts include evaluation of anode contaminants, materials development, advanced manufacturing, materials characterization, and failure analysis.

Core Technology—This key technology conducts applied research and development on technologies—exclusive of the cell components—that are critical to the commercialization of SOFC technology. Efforts are focused on developing and implementing advanced technologies to improve the reliability, durability, and robustness of the SOFC stack; identifying and mitigating stack-related degradation issues; cost reduction; and computational tools and modeling.

System Development—System developers are independently developing unique and proprietary SOFC technology suitable for use with natural gas or coal-derived syngas. They are responsible for validating technology evolving from the Cell Development and Core Technology R&D, cell development and manufacturing, scale-up of cells and stacks for aggregation into modules, hardware development, manufacturing process development, commercialization of the technology, and market penetration. Within the Systems Development Key Technology is an Innovative Concepts initiative that supports the RD&D of SOFC technology that has the potential to surpass current anode-supported planar SOFC technology in terms of cost and reliability. Program participants are developing novel cell and stack architectures and/or material sets. This next-generation SOFC technology in the near-term includes nominally 5-10 kWe-scale stack tests using cells envisioned in the developer's future commercial systems. These strategically oriented research projects may offer significant cost reductions post-2020.

Figure 2. Photo Courtesy FuelCell Energy

Figure 3. Photo courtesy LG Fuel Cell Systems

PROGRAM DEVELOPMENT TIMELINES

The state-of-the-art anode-supported planar SOFC technology, under development for more than 15 years, has matured to the point that cell performance, degradation, and reliability are acceptable for entry into service. State-of-the-art developers have validated their respective technology through progressively larger stack tests and are acquiring system integration and operational experience via larger scale, fully integrated system tests. Two proof-of-concept SOFC power systems, fueled by pipeline natural gas, were successfully demonstrated by FuelCell Energy (FCE) and LG Fuel Cell Systems (LG), respectively. FCE built and tested a 50-kWe SOFC power system (Figure 2) integrated into the electrical grid, producing ~50 kWe of AC power at 55 percent electrical efficiency (HHV) with a degradation rate of 0.9 percent per 1,000 hours over 1,500 hours of operation. LG built and tested a pressurized SOFC power system (Figure 3) integrated into the grid, delivering ~200 kWe of AC power at 57 percent efficiency (HHV).

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Two 200 kWe SOFC prototype field tests are presently under design and construction. Startup of the first system is expected in Fiscal Year 2018 (FY18). These two projects will field test, in an operational environment, natural gas fueled SOFC power systems that are expected to be representative of entry-into-service systems. The satisfactory operation of these systems is necessary to validate the technology at large scale prior to embarking on the MWe-class demonstration.

A MWe-class demonstration program will commence in FY18 when funding is expected to be available for the design of up to three MWe-class systems. Construction and testing will follow in FY20. The MWe-class demonstrations will establish the technology foundation and operational experience necessary for large-scale and longer-term multi-MW demonstrations. Cost-competitive MWe-class distributed generation systems are expected to be commercially available in the early-to-mid 2020s.

In parallel, the SOFC Program will continue RD&D, through the Innovative Concepts initiative, into the next generation of SOFC technology and conduct progressively larger stack and systems demonstrations. A 10-MWe demonstration with carbon capture and storage (CCS), in the mid-2020s, will incorporate the most recent advancements in SOFC technology and will operate on a slipstream from an IGCC or natural gas combined cycle (NGCC) system.

The SOFC Program technology development will culminate with a first-of-a-kind, utility-scale pilot, integrated with either an IGCC or NGCC system with CCS in 2030–2040 (Figure 4).

Additional information may be found on NETL's Solid Oxide Fuel Cell web page.

SOFC Development Timeline

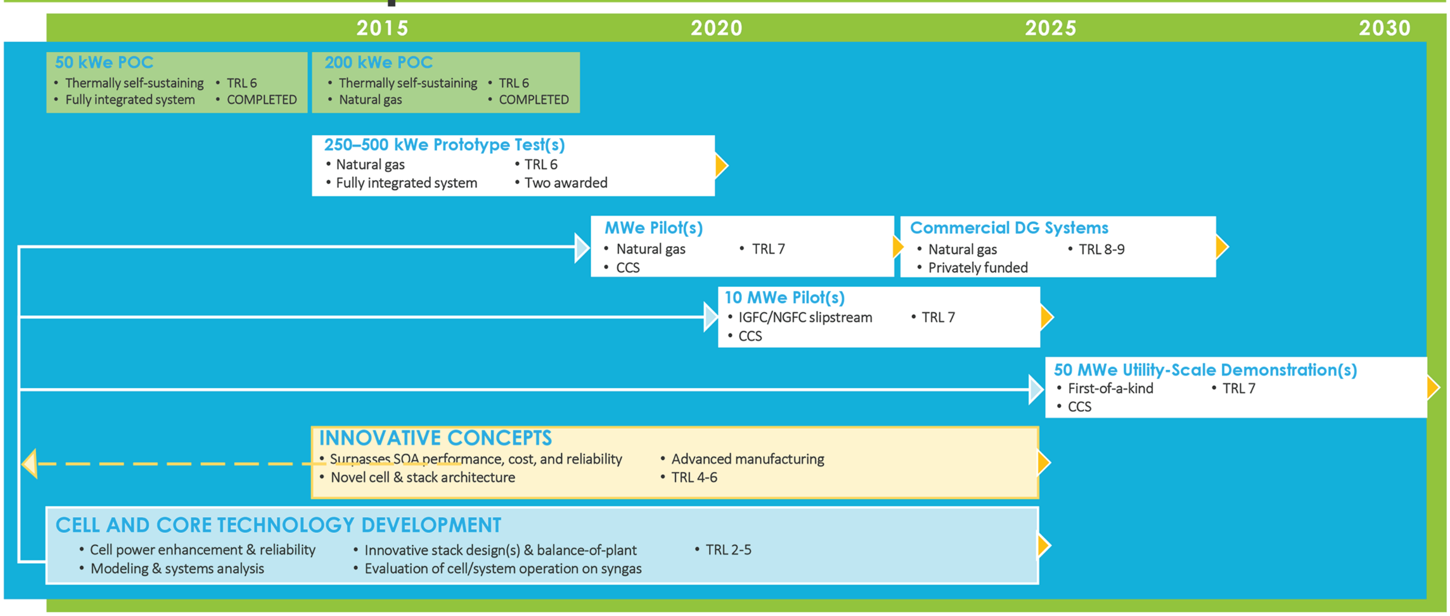

Figure 4.

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