I. INTRODUCTION

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Competitive Innovation: Accelerating Technology Development

The U.S. Department of Energy (DOE) Office of Fossil Energy, through the National Energy Technology Laboratory (NETL) and in collaboration with private industry, universities and national laboratories, has forged Government-industry partnerships under the Solid State Energy Conversion Alliance (SECA) to reduce the cost of solid oxide fuel cells (SOFCs). This fuel cell technology shall form the basis for integrated gasification fuel cell (IGFC) systems utilizing coal for clean and efficient central power generation. IGFC systems incorporating SECA SOFC technology address environmental, climate change, and water concerns associated with fossil fuel use while simultaneously establishing a foundation for a secure energy future in the United States.

With the successful completion of the first phase of the SECA Cost Reduction program element in 2006, where initial cost and prototype test goals were achieved, SECA moved one step closer to realizing its vision of cost-effective, near-zero-emission fuel cell technology for commercial applications. SECA moved another step closer in 2009, when two of the Industry Teams successfully completed the first phase of Coal-Based Systems validation testing – metric tests for 10 kilowatt (kW) stacks in accordance with the SECA minimum requirements of greater than 5,000 hours of operation and degradation of less than 4.0 percent per 1,000 hours (<4%/1,000 hr). In the final quarter of Fiscal Year (FY) 2010, the Industry Teams will progress further with testing of ≥25 kW stacks to validate achievement of SECA's cost goals of $175/kW (stack) and $700/kW (power block). These cost goals are based upon high-volume production in 2007 dollars.

Successful validation testing in accordance with rigorous DOE guidance reflects the excellent progress being made toward the SECA goals. A coal-based SOFC power generation system that meets the goals will achieve environmental regulations compliance with effectively no carbon footprint, near-zero water requirements, essentially zero nitrogen oxides (NOx), and the lowest available cost of electricity. This technology makes substantial strides in realizing clean, economic energy production from coal in any state in the United States.

The SECA fuel cell program is a critical element of the DOE's Office of Fossil Energy technology portfolio. From an energy security perspective, coal is a primary resource for reducing dependence on imported oil and natural gas. More than half of the nation's electricity supply is generated from coal – developing technology to ensure its environmentally clean and climate friendly use is of crucial national importance. SECA technology offers greater than 99 percent carbon capture, less than 0.5 parts per million (ppm) NOx emission, reduced water requirements, and a coal-to-electricity efficiency exceeding 50 percent on a higher heating value (HHV) basis and as high as 60 percent HHV for advanced pressurized systems. The SECA cost goals of $175/kW stacks and $700/kW power blocks (2007 U.S. dollar basis) pursued under the SECA Cost Reduction program element will ensure that the cost of electricity to the user will not exceed what is typical today. Concurrently, the SECA Coal-Based Systems program element will scale and integrate SECA SOFC technology for use in large IGFC systems. Cross-cutting research and development (R&D) and testing support are provided by SECA's Core Technology Program element.

SECA is comprised of three groups: Industry Teams, Core Technology Program participants, and federal government management. The Industry Teams within the SECA Cost Reduction and Coal-Based Systems program elements design the fuel cells and handle most hardware and market penetration issues. The Core Technology Program element, made up of universities, national laboratories, small businesses, and other R&D organizations, addresses applied technological issues common to all Industry Teams. Findings and inventions under the Core Technology Program are made available to all Industry Teams under unique intellectual property provisions that serve to accelerate development. The federal government management facilitates interaction between Industry Teams and the Core Technology Program as well as establishes technical priorities and approaches.

Across the United States, SECA Core Technology Program participants are working on dozens of fuel cell projects, led by the brightest minds from leading universities, national laboratories and businesses. These competitively-selected projects provide vital R&D and testing in support of the Industry Teams.

In the same spirit of healthy competition, the Industry Teams leverage the collective ingenuity of the Core Technology Program to independently pursue innovations in fuel cell design that can be mass-produced at lower cost. Focusing on Cost Reduction and Coal-Based Systems, the Industry Teams are working to solve the challenges of fuel cell technology, each using different design and manufacturing approaches. As a result, the SECA program is rich in innovation, allowing it to reach its goals much faster.

Fuel Cell Research and Development

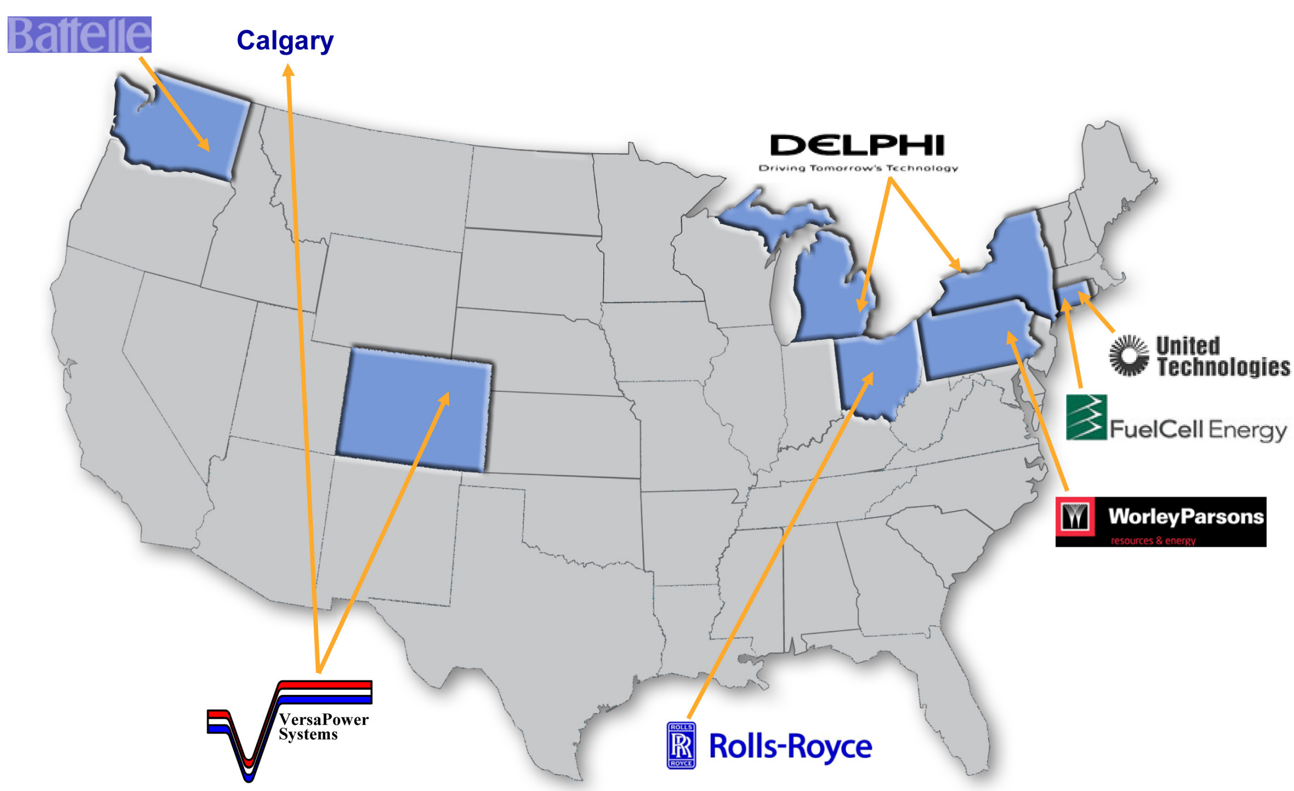
The Office of Fossil Energy and NETL are pleased to present this FY 2010 Fuel Cell Program Annual Report, a compilation of abstracts from the fuel cell projects managed through these offices. These abstracts are divided into subsections as detailed in the following.

SECA Industry Teams — Coal-Based Systems

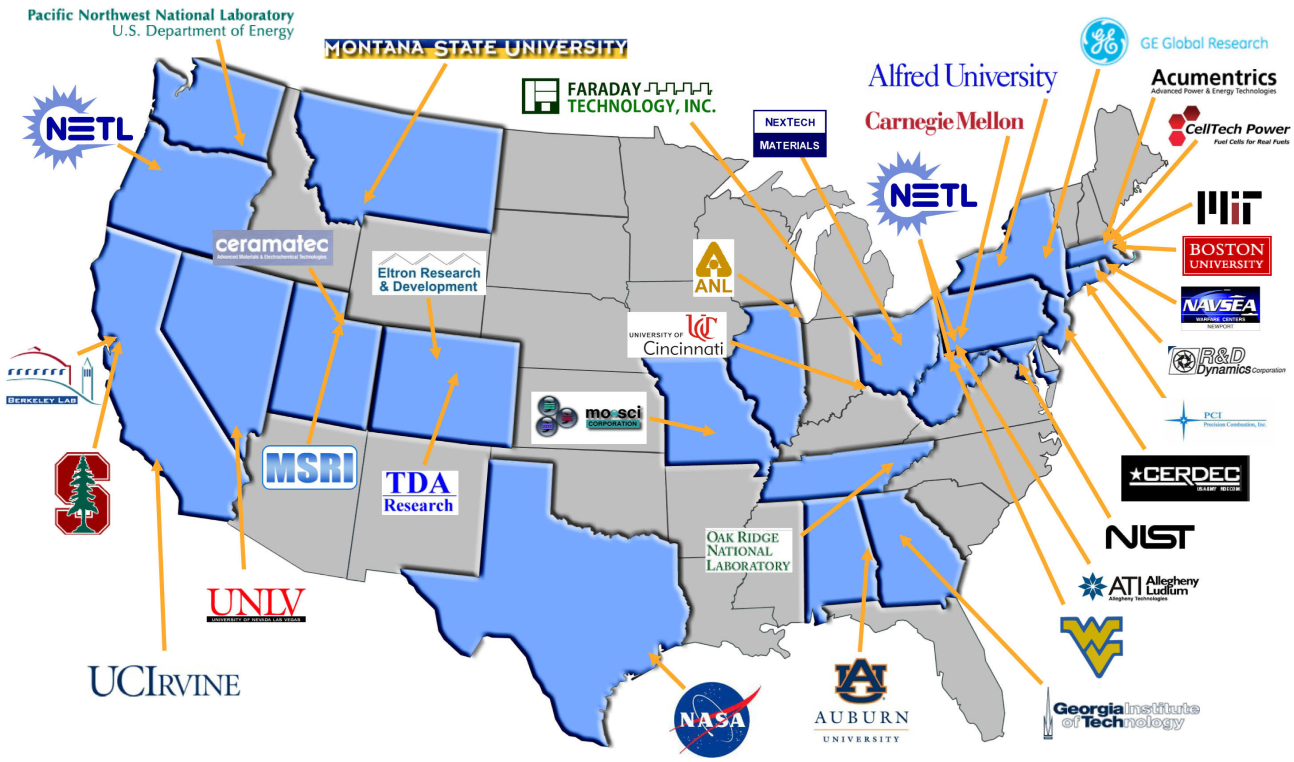
Through its Coal-Based Systems program element, SECA seeks to leverage successes in the Cost Reduction program element; scale SOFC cells and stacks to sizes appropriate for central power generation applications; and integrate the SOFC, associated balance of plant, and coal gasification technology to create an IGFC system. Industry Teams will focus on developing large megawatt-scale systems while continuing SECA Cost Reduction activities. It is anticipated that the best technology from any Industry Team will be available for incorporation into one or more of the SECA Coal-Based Systems projects. Key R&D topics include materials (cathodes, interconnects, seals, etc.), manufacturing, failure analysis, system integration, coal contaminants, balance of plant, controls and instrumentation, and pressurization.

SECA Industry Teams — Cost Reduction

To achieve cost targets, Industry Teams are refining and validating advanced technology in ≥25 kW SOFC stacks that can be mass-produced, aggregated, and scaled to meet a broad range of applications. This development



SECA Industry Teams and Major Subcontractors



SECA Core Technology Program and Other R&D Participants

activity is blending established manufacturing processes with state-of-the-art fuel cell technology advancements in order to leverage the advantages of economies of production (high-volume mass production) and scale to reduce fuel cell costs. Achieving the cost targets requires reaching a full spectrum of large markets, such as auxiliary power units (APUs) for trucks and recreational vehicles, as well as other markets such as residential-commercial-industrial power, a wide range of distributed generation, and specialized applications for the military. Adoption of common stack technology for these vast markets will create the opportunity for the high-volume production required to reduce cost to commercially viable levels.

SECA Core R&D

The Core Technology Program provides comprehensive applied research support in nine focus areas. This program structure, along with special intellectual property provisions (exception to the Bayh-Dole Act), reduces R&D cost by leveraging resources so that the Industry Teams do not engage in separate, redundant applied research projects, paying multiple times for the same technical solutions. Diligent DOE management of the Core Technology Program with this approach also ensures that only major issues are addressed. SECA's goal is to raise the technology bar in large strides rather than small steps. Core Technology Program areas of research are also funded by special topics under DOE Small Business Innovation Research (SBIR), Small Business Technology Transfer, and Experimental Program to Stimulate Competitive Research solicitations. The Core Technology Program focus areas include the following:

- **Cathodes** – Improve the stability and performance of fuel cell cathodes using state-of-the-art concepts and methodologies.
- **Anodes and Coal Contaminants** – Determine potential coal syngas contaminants and their impact on anode performance.
- **Interconnects and Contact Materials** – Develop stable, low-cost metallic interconnects and interconnect contact materials operating in the temperature range of 650 to 850°C with acceptably low area-specific resistance (ASR) and stability over the service lifetime.
- **Seals** – Develop materials and designs exhibiting adequate sealing performance with the requisite chemical and phase stability in long-term service.
- **Cross-Cutting Materials and Manufacturing** – Develop materials and manufacturing technologies

that improve fuel cell reliability, performance, and ability to tolerate any fuel or air contaminants, and that achieve cost reductions.

- **Fuel Processing** – Develop fuel processing technologies that will meet application requirements such as zero water consumption, space and volume constraints, and transient capability.
- **Power Electronics** – Optimize efficiency and cost in conversion of fuel cell output to usable DC (direct current) and AC (alternating current) power.
- **Modeling and Simulation** – Create models to determine a reliable operating space and to guide manufacturing.
- **Balance of Plant** – Develop high-temperature heat exchangers and blowers to enable high system efficiency and low cost.

Innovative Concepts

SECA Innovative Concepts will assess the feasibility of a coal power plant based upon a direct coal SOFC and will validate the performance, robustness, cost and scalability of metallic supported cell designs for use in coal-based SOFC power systems.

Advanced Research

The SECA Advanced Research program provides cross-cutting, multidisciplinary research that leads to advanced electrochemical technologies minimizing the environmental consequences of using fossil fuels in energy generation. This program supports future advances in the SECA and Office of Fossil Energy Coal and Power programs by developing novel electrochemical energy-conversion and integrated technologies that advance the efficiency, reliability, and cost goals of fuel cell systems.

Key Program Accomplishments

SECA Industry Teams – Coal-Based Systems

SOFC Developers Achieve New Milestones in System Efficiency and Cost by Implementing the Next Generation of Thin Cell Technology. FuelCell Energy, Inc. and its technology partner, Versa Power Systems, Inc. initiated the manufacturing of new SOFC technologies based on improved materials and thinner anode structures. The new generation of cells has demonstrated significant performance gains, an expanded range of operating temperature, and long-term stability as compared to the previous baseline technology. The cell manufacturing process is based on tape-casting, screen-printing, and co-firing processes that have been optimized to take advantage of the new materials and thin cell technology. Over 46 stacks have been fabricated and tested, with cell sizes up to 1,000 cm^2 and cell counts up to 92 cells. A recent milestone in technology development was achieved by fabrication and testing of the first-of-a-kind >30 kW stack tower based on anode-supported planar cells. This significant achievement paves the road for future large-scale SOFC power stations and distributed generation systems. Utilizing the improved class of cell and stack technologies, a nominal 400 megawatt (MW) coal-based baseline system was developed. The system offers 58.7% electrical efficiency based on high heating value of coal while capturing more than 99% of carbon in the syngas as carbon dioxide. The baseline SOFC system consumes 75% less water compared to pulverized coal combustion plants using scrubbing technologies for carbon capture and has a footprint comparable to integrated gasification combined cycle plants. The recent factory equipment cost estimates have shown an SOFC power island cost of $414/kW in 2002 dollars, approaching the DOE cost target for a coal-based system.

Power Density Further Increased and Durability Improved for Solid Oxide Fuel Cells Targeted for Centralized Coal-Based Power Plants. Rolls-Royce Fuel Cell Systems (RRFCS) has demonstrated higher power densities for its integrated planar SOFC, reducing the cost of power block modules for an integrated coal-gasification fuel cell combined cycle plant that is projected to allow sequestration of 90% of carbon dioxide and achieve an overall efficiency of >50%. Further improvement by 36% of the power density at normal system operating conditions has been achieved through substitution and modification of the active layers of the cell. With this 2009-2010 advancement, the power density has now increased 73% cumulatively over the course of the SECA program. Operation of fuel cells at higher power densities allows smaller overall fuel cell systems at equivalent power ratings, which cascades into an overall lower cost for the power plant and lower cost of electricity. Coincident with the performance improvement has been improvement in the long-term durability achieved through mitigation of a key degradation mechanism present within the electrical interconnect formed between adjacent cells. System modeling studies have resulted in selection of a revised cycle for operation of the pressurized Rolls-Royce SOFC system as part of an advanced IGFC plan. The IGFC cycle is now common to that required for the 1-MW distributed power generation product under development by RRFCS, allowing a nearer-term validation to utilities of the commercial readiness of SOFC technology demonstration prior to adoption at the larger scale as required for the IGFC. Rolls-Royce has produced fuel cell modules on their pilot production line in Canton.

SOFCs Successfully Scaled for Large-Scale Stationary Applications. UTC Power is developing conceptual process designs of a wide range of power systems ranging from 250 kW up to 100+ MW with a focus on meeting the system efficiency and carbon separation targets specified in the SECA minimum requirements. Delphi, in partnership with Battelle Memorial Institute under the SECA Cost Reduction program, has continued advancement of SOFC technology. Cell and stack fabrication capabilities have been expanded and scaled up to high rates with improved process controls to maintain the highest quality standards. An improved 4th generation cell design with increased active area has been fabricated and tested. Power density has exceeded SECA 2011 goals with performance of 0.81 V/cell using 48.5% H_2, 48.5% N_2, 3% H_2O fuel. Utilizing the new cell design, a 25-cell stack has been built and demonstrated to produce power in excess of 5 kW. The Gen 4 stack is being used as the basis for a proof-of-concept power plant being developed by UTC Power. Phase I test results on simulated coal gas will be used to validate models that have been developed to aid in the design of the stationary SOFC power module.

SECA Industry Teams – Cost Reduction

SOFCs Successfully Tested for Coal-Based System Analysis. Delphi, in partnership with Battelle Memorial Institute under SECA, successfully fabricated and tested two 30-cell Generation 3.2 stacks. The stacks were instrumented with thermocouples on dummy repeating units to measure internal stack temperatures, as well as temperatures at the inlet and outlet of the stack. A stack test stand was also updated to run various load profiles and simulated coal syngas compositions as part of the project. Data were collected, analyzed, and reported to SECA. These data on the operation of state-of-the-art SOFC stacks shall be used for model validation and calibration in order to assess the impact of stack and system operating conditions on cell temperatures.

SECA Core R&D – Cathodes

Correlations Between Electrical Conductance and Lattice Parameter of SOFC Cathode Materials Discovered. Measurements of the out-of-plane lattice parameter of a $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ (LSCF) thin film and its electrical conductance at Argonne National Laboratory have revealed time-dependent changes in both of these quantities in response to an applied direct current electrical field. Experiments were performed that simultaneously measured X-ray diffraction along with conductance from an (001) oriented 20 nm LSCF film grown on a 100 nm gadolinium-doped ceria (GDC) (001) film deposited on a yttria-stabilized zirconia (YSZ) (001) substrate. The LSCF film was found to expand normal to the surface as oxygen partial pressure was decreased, or as a negative cathodic potential was applied to the LSCF/GDC/YSZ stack. A simultaneous measurement of the conductance during the application of this negative cathodic potential revealed a rapid decrease, then a plateau, followed by another rapid decrease in conductance. This two-step drop indicates that more than one process controls the conductance of these LSCF thin films. The length of the plateau generally becomes shorter as the applied bias becomes more negative and as the temperature is increased from 500°C to 700°C, but more studies are required to confirm this behavior. The kinetics of the lattice parameter change becomes much faster after the conductance has plateaued and then dropped. The size of the lattice parameter change, and hence the inferred oxygen vacancy concentration change, is only weakly dependent on temperature.

Role of Structure, Surface Chemistry, and Oxygen Reduction in SOFC Cathode Materials Investigated. Over the last year, using X-ray absorption spectroscopy (XAS), Boston University has clearly shown the charge state of the Mn ion in lanthanum strontium manganite (LSM) to be closely related to the cathode polarization resistance changes as measured by impedance spectroscopy. Further, using O-edge XAS, Boston University has shown segregation of Sr to the surface of the LSM thin films under cathodic conditions and confirmed these results using total X-ray fluorescence. Using electrical conductivity relaxation experiments and diffusion experiments, the surface exchange coefficient on epitaxial LSM thin films was measured and found to be 4×10^{-9} cm/s, and the diffusivity of oxygen was shown to be on the order of ~5×10^{-9} cm^2/s at 800°C. In the next phase of the project, Boston University expects to correlate oxygen transport kinetics to the thin film surface structure using in situ X-ray experiments.

Surface Engineered Films of Cathode Materials Produced and Characterized. Carnegie Mellon University (CMU) has demonstrated that surface engineered films of cathode materials can be produced and their structural and chemical properties characterized in detail. Crystallographic anisotropies were observed for epitaxial LSM single-crystal films in their oxygen uptake kinetics, where low index orientation varies by a factor of 4 in SOFC conditions. Furthermore, the surface exchange coefficient can vary greatly at low thicknesses and as a function of the support (substrate), both of which are relevant for SOFC electrocatalysis. Both electrical conductivity relaxation (ECR) and Kelvin probe spectroscopy (KPS) equipment can be used to simultaneously measure oxygen uptake, indicating that chemisorption and incorporation can be distinguished when their time constants are significantly different, as observed for LSM. CMU will continue to produce a series of surface engineered films and will investigate (1) their structural properties, (2) their stabilities, and (3) their oxygen uptake kinetics using ECR and KPS measurements. By fabricating a matrix of related materials and carrying out these measurements, CMU will be able to provide a large amount of data to determine the key parameters that correlate surface structure to surface activity.

Method Developed for Predicting New Cathodes. Eltron Research & Development Inc. has demonstrated an approach for predicting potentially good cathode electrocatalyst formulations using existing experimental data. The use of artificial neural networks (ANNs) provides an input section, initial predictor of performance and properties of compositions selected, and a down-selection filter for a more complete structure and properties prediction system to be developed in Phase II. The model being developed relates physicochemical descriptors to cathode performance or to a metric proportional to it. Performance was fit to a function of the descriptors using an ANN, which can predict, classify, and cluster performance results. This approach allows for materials properties prediction and also enables prediction of material structure and structure-property relationships from the input of a proposed material composition. Using this approach, no fewer than four candidate materials were identified which should possess oxygen electroreduction activity comparable to or better than existing cathode materials.

Catalyst Infiltration of Cathodes Promises Improved Performance and Stability. Georgia Institute of Technology has demonstrated that the performance and stability of an LSCF cathode can be enhanced by infiltration of a catalyst such as LSM, scandia-doped ceria, or lanthanum calcium chromite. Microanalyses of the structure, composition, and morphology of the surfaces and interfaces in an LSM-infiltrated LSCF cathode reveal that a thin (~50 nm) LSM film is relatively stable on the surface of an LSCF substrate after annealing at 850°C for 900 hours, although the regularity of atom arrangement in the outer layer of the film was reduced from long to short range order. The inner layer of the LSM film and the underlying LSCF maintain their respective crystal structures and their structural coherence. For an LSM-infiltrated porous LSCF cathode, an amorphous layer (~2 to 20 nm) was formed on the surface of LSCF grains. Energy dispersive X-ray spectroscopy analysis of the amorphous layer suggests that it contains La, Sr, Co, Fe, and Mn; this surface lanthanum strontium cobalt iron manganite (LSCFM) layer may have enhanced oxygen ion conductivity due to the disorder of the high concentration of defects. Also, there was no evidence that Sr was enriched near LSCF surfaces. Thus, the resulting coating of LSCFM not only promotes facile transport of oxygen ions to the underlying LSCF but also inhibits formation of Sr-oxide on the LSCF surfaces. Considering the improvement in performance and stability achieved by infiltration, it is anticipated that the implementation of catalyst-infiltrated cathode may help to meet DOE cost goals.

Promising Cathode Contact Materials Identified. Lawrence Berkeley National Laboratory (LBNL) is undertaking a new project in FY 2010, addressing cathode contact material selection and development. The primary challenge addressed during FY 2010 concerns electrical connection and bonding between the interconnect and SOFC cathode layers. Historically, cathode materials such as LSM have been used as a cathode contact material (CCM) paste to bond the cell to the interconnect. High temperature is typically required to achieve good bonding, however, leading to rapid oxidation of the stainless steel interconnect. If a temperature low enough to avoid oxidation of the steel (<1,000°C) during the bonding step is employed, poor bonding and eventual delamination of the contact material occur. The goal of the work at LBNL is to identify candidate cathode materials displaying adequate properties after bonding at <1,000°C. A list of candidate cathode contact compositions was purchased from Praxair or fabricated by a glycine nitrate process. The properties of primary relevance, including conductivity, sintering behavior, coefficient of thermal expansion, and reactivity with manganese-cobalt spinel (MCO) and LSCF, were then determined. The summary of this screening effort suggested that the most promising candidates are LSCF and lanthanum strontium copper ferrite (LSCuF) (chosen for extensive sintering at low temperature) and strontium samarium cobaltite and lanthanum strontium cobaltite (LSC) (chosen for high conductivity). These four materials were then incorporated into ASR specimens in which electrical resistance of the LSCF/CCM/MCO junction was monitored over time. LSC and LSCuF are the most promising compositions tested to date. They provided low and stable ASR for 200 hours at 800°C. LSCuF survived 5 thermal cycles at 10°C/min.

Cathode Surface Electronic Structure and Chemical State Probed. Massachusetts Institute of Technology has probed the evolution of the surface topographic and electronic structure and chemical state of $La_{0.7}Sr_{0.3}MnO_3$ thin films using scanning tunneling microscopy and spectroscopy and X-ray photoelectron spectroscopy at elevated temperature and reactive gas environment, in particular to identify the structural nature of surface segregation on LSM. A layer-by-layer structure was found with a step height of 3.9 Å, close to the lattice parameter of LSM. Up to 500°C, the topography and the step heights remained the same, statistically within 2-4%, implying that no phase separation took place on the top layers of the film. The low oxygen pressures, down to 10^{-10} mbar, at elevated temperatures promoted segregation of Sr by 12-20% on the A-site, accompanied by a smaller increase of (La+Sr)/Mn. The results suggest two possible structures for Sr segregation: the replacement of La by Sr on the AO-surface of the LSM, which retains a perovskite termination, or a separate AO-oxide phase nucleating on the defected lower layers. The electronic structure on LSM surface transitions from semiconducting to metallic at high temperatures, and the electron tunneling is affected by the partial pressure of oxygen.

Non-Destructive Characterization of Surfaces and Interfaces of SOFC-Related Materials Continued in Order to Identify Surface and Interface Properties during SOFC Operation. Using X-ray absorption spectroscopy and X-ray resonant scattering in the soft-X-ray energy region, Montana State University has compared the elemental distribution and chemical state of pristine and degraded LSCF/GDC interfaces, showing that prolonged operation of the cell results in La cation motion in these regions, strongly modifying the A-site and B-site occupancies of the La and Sr as well as the electronic structure of the Fe atom (due to a modification of the tetragonal distortion of the oxygen cage around the Fe atom). Furthermore, the degradation is dependent on operational conditions, especially the local cell potential occurring predominantly on the oxygen ion in-flow side. The potential at the surface of the LSCF is observed to modify the valency of surface transition metal atoms (here Cr is used as a tag element to clearly demonstrate the surface valency change from trivalent Cr to hexavalent Cr).

Infiltration Parameters for High-Activity SOFC Cathode Established. Researchers at the National Energy Technology Laboratory completed an initial study establishing experimental conditions of infiltration processes intended to tailor the microstructure of a Sr- and Co-doped $LaFeO_3$ cathode of an SOFC. The infiltration technique introduces nano-sized particulates of pyrochlore-structured $(LaSr)_2Zr_2O_7$ and perovskite-structured $(LaSr)CoO_3$ throughout the electrode pore surface to improve electrode reactivity. Experimental parameters, including concentration of infiltrate solution, infiltrate dosage, calcination temperature, and backbone structure, were scrutinized for the infiltrates to generalize the relationship between the evolved microstructures and cell performance. By applying the infiltration process to the cathode of a standard commercial button cell (MSRI Co.), researchers have decreased the ASR of cathode polarization from 0.68 ohm·cm^2 in the uninfiltrated cathode to 0.27 ohm·cm^2 in the infiltrated cathode. Based on the accumulated data and understanding, researchers expect to suggest required infiltration conditions for a specific electrode system, which is defined by its composition and microstructure.

New Cell Characterization Capability: In Situ High-Temperature X-Ray Diffraction (XRD) Analysis of Operating SOFC Cathodes. A test stand has been developed at Pacific Northwest National Laboratory that allows anode-supported SOFCs to be operated in the heating chamber of a high-temperature X-ray diffractometer. This allows for collection of XRD spectra of SOFC cathodes under actual operating conditions. The initial test configuration, which included a fine gold mesh current collector above the cathode, only allowed for very weak detection of LSCF-6428 diffraction peaks. Improved results were obtained by applying a gold paste current collector only to the perimeter of the cathode and by narrowing the width of the beam so that it impinges only on the cathode and not on the current collector around its edges. Due to the small diameter of the cathode, this configuration provides adequate current collection and also produces strong XRD patterns of the cathode material. It is anticipated that this capability will allow for detection of changes in cathode structure and/or secondary phase formation which may occur during long-term cell operation.

Study of the Electronic Structure of Cathode Materials Promotes Understanding of Oxygen Incorporation into Fuel Cell Cathodes. A theoretical study of oxygen on manganite surfaces conducted by Walter Harrison of Stanford University suggested a new understanding of the incorporation of oxygen into fuel cell cathodes. Oxygen is now understood to adhere to the surface as neutral atoms or molecules, then enter neutral oxygen vacancies, or F centers, without the successive ionization steps usually assumed. These neutral oxygen vacancies in the cathode are supplied by the neutralization of positively charged electrolyte vacancies at the electrolyte-cathode interface. Understanding of these mechanisms followed from the calculation of the electronic structure of the oxygen, of the cathode substrate, and of the interaction between the two. The limiting step in the process appeared to be the tendency of the adsorbed oxygen to avoid sites adjacent to oxygen surface vacancies. There is hope that further understanding may lead to a way to circumvent this limitation.

SECA Core R&D – Anodes and Coal Contaminants

Perovskite Adsorbents for Arsenic and Phosphorus Removal from Coal-Derived Synthesis Gas Streams Successfully Produced. During Phase I research in FY 2010, Eltron Research & Development, Inc. finished the design, synthesis, and initial testing of perovskite-based adsorbents for the removal of arsenic and phosphorus from coal-derived synthesis gas in order to protect Ni in

SOFC anodes from these poisons. The sorbents were designed to form both thermally and chemically stable arsenides and phosphides in order to prevent the re-release of these poisons at high temperatures or during interactions with high-pressure steam. Preferred sorbents produced at Eltron demonstrated As and P *adsorption efficiencies* as high as 73% versus 47% for a commercial Cu/ZnO material under ambient pressure and at 300°C under an argon stream containing 300-800 ppm As and 30–250 ppm P flowing at 2,000 hr^{-1}. Preferred sorbents also demonstrated As and P *adsorption capacities* as high as 4.5% versus 1.0% for a commercial Cu/ZnO material under ambient pressure and at 300°C under an argon stream containing 300-800 ppm As and 30–250 ppm P flowing at 2,000 hr^{-1}. Eltron sorbents contain no noble metals and are projected to cost <$5/lb on an industrial scale.

Thermodynamic and Experimental Analysis of SOFC Anode and Trace Coal Material Interactions Completed. A thermodynamic analysis of the interactions of trace materials present in coal syngas with the anode of a SOFC was performed in detail at the National Energy Technology Laboratory using a survey of 15 common gasifiers. The analysis shows that the bulk syngas composition affects the extent of anode secondary phase formation, with arsenic, phosphorus, and antimony combining with nickel to form the primary reaction products. These products are known to degrade fuel cell performance, and therefore need to be understood in order to predict fuel cell performance. The information gained from the analysis will be used to design effective clean-up strategies for integrated fuel cell/gasification systems. A paper describing this work was accepted for publication in the Journal of Power Sources.

A technique was developed that provides measurement of trace metal present in liquid- and/or gas-phase process streams at concentrations below 1 part per billion (ppb). The technique uses a modified gas chromatograph – inductively coupled plasma/mass spectrometer (GC-ICP/MS), which reduces the time required for sample collection and analysis by a factor of 50 compared to established methods. To perform the analysis, kinetic energy discrimination (KED) factors were developed to correlate a known spike of cesium (^{133}Cs) to all other analytes in liquid-phase samples. The KED factors were then used to simultaneously test an "unknown" sample of 44 liquid-phase analytes, each with a concentration of 10 ppb (mass), and 2 gas-phase analytes, each with a concentration of 1 ppm (vol), using ^{133}Cs as an internal standard. The technique's accuracy compares favorably to traditional ICP/MS methods, and concentration within 50% of the actual value for the liquid-phase analytes and 30% for the gas-phase analytes was measured. This new approach allows improved response when measuring trace components in coal syngas or flue gas, which is important for assessing clean-up requirements for advanced coal power production systems, including integrated gasification and fuel cell technology.

SECA Core R&D – Interconnects and Contact Materials

Coated Ferritic Stainless Steels Improve SOFC Performance and Cost Efficiency. In an interagency and industrial-partner collaboration, researchers at the National Energy Technology Laboratory (NETL), ATI Allegheny Ludlum Corp., and Pacific Northwest National Laboratory have successfully modified the metallic alloy AISI 441 to help achieve SOFC electrical interconnect requirements for lifetimes of 40,000 hours or more. AISI 441 is an inexpensive ferritic stainless steel. Experimental work at Pacific Northwest National Laboratory and ATI Allegheny Ludlum indicated that, with a special coating, AISI 441 exhibits very low and nearly constant area-specific resistance throughout 5,000 hours of testing. A rare earth treatment integral to the special coating and a manufacturing process that reduces silica formation have been developed by NETL and ATI, respectively. In addition to these breakthroughs, the cost of commercially available AISI 441 is predicted to be considerably lower (~$3.10/lb) than the cost of producing state-of-the-art high-temperature metal alloys suitable for SOFC electrical interconnect service.

Innovative Process for Application of $(Mn,Co)_3O_4$ Spinel Coatings onto SOFC Interconnects Demonstrated. Faraday Technology and West Virginia University are developing a cost-effective manufacturing process for application of $(Mn,Co)_3O_4$ spinel coatings onto SOFC interconnects to minimize chromia scale growth and chromium evaporation that can cause unacceptable degradation in the SOFC electrochemical performance. The manufacturing process involves using pulse reverse electrodeposition for application of a Mn-Co alloy coating onto the interconnect surface and subsequent conversion to the $(Mn,Co)_3O_4$ spinel. Faraday Technology and West Virginia University demonstrated that the electrodeposition process could produce uniform, dense, crack-free, well-adhered Mn-Co alloy coatings of various compositions on a 5 cm x 5 cm T441 stainless steel interconnect surface. A post-deposition thermal treatment converted the Mn-Co alloy coatings to $(Mn,Co)_3O_4$ spinels in which a coating thickness of ~3 μm was shown to be sufficient to mitigate chromia diffusion after 500 hours of thermal exposure at 800°C. A preliminary economic analysis based on using batch manufacturing for the pulse reverse electrodeposition process demonstrated that the innovative coating technology can meet DOE's high-volume target of 1,600,000 plates per annum for 250 MW of fuel cell stacks at a cost of ~$1.87 per 25 cm x 25 cm coated interconnect.

Long-Term Evaluation of Protective Interconnect Coatings Exceeds 1 Year. In previous work at Pacific Northwest National Laboratory, $(Mn,Co)_3O_4$ (MC) spinels have been systematically investigated and applied as protection layers on a variety of candidate SOFC interconnect steels. Recently, the primary emphasis has been on the application of spinel coatings to AISI 441 ferritic stainless steel, which is being investigated as an interconnect alloy. A Ce-modified version of the coating has been developed to improve the interfacial adhesion between the steel substrate and the oxide scale that grows beneath the spinel coating. Long-term tests of Ce-modified MC spinel coatings on AISI 441 ferritic stainless steel indicate that these coatings exhibit low, stable ASR for over 10,000 hours at 800°C (tests are still in progress). Also, ongoing tests at 850°C indicate low, stable ASR for over 4,000 hours. In related work, an ultrasonic spray process has been developed for fabrication of MC spinel coatings onto steel interconnects and cell frames. Using a Design of Experiment approach, the preferred slurry and spray parameters for application and heat treatment of MC coatings onto 441 stainless steel were identified. Both wide and narrow mode spray processes have been optimized. ASR testing of the sprayed coatings indicated excellent performance comparable to previous coatings applied via screen-printing methods. Also, in an effort to reduce materials cost, coatings with reduced Co content are being evaluated. Co-free (Mn oxide only) coatings exhibited low initial ASR, but the ASR increased steadily over time at an unacceptably high rate. On the other hand, preliminary results for coatings with reduced Co content (i.e., Co:Mn ratio less than the standard 50:50 molar ratio) showed much improved stability over the Mn oxide coatings.

Multi-Site Doping of Yttrium Chromite Results in Optimized SOFC Interconnect Properties. The effect of cobalt, nickel, and copper doping on thermal, structural, and electrical characteristics of calcium-doped yttrium chromite was studied at Pacific Northwest National Laboratory. Yttrium chromite doped with 20% Ca on A-site and up to 30% cobalt, 15% nickel, and 10% copper on B-site showed a single-phase orthorhombic perovskite structure between 25 and 1,200°C over a wide range of oxygen partial pressures. A small amount of copper doping (~2%) remarkably enhanced sinterability, and the electrical conductivity was significantly improved by cobalt and nickel doping. Nickel doping stabilizes defect structure towards reduction, resulting in improved electrical conductivity and dimensional stability in reducing atmosphere. The thermal expansion coefficient can be adjusted and closely matched with that of 8 mol% YSZ through an optimum amount of doping, and oxygen ion leakage current due to exposure to dual atmospheres was shown to be acceptably low using oxygen permeation experiments. A chemical compatibility study between $Y_{0.8}Ca_{0.2}Cr_{0.85}Co_{0.1}Ni_{0.03}Cu_{0.02}O_{3\pm\delta}$ and other cell components indicated that the formation of detrimental secondary phase is not expected at processing temperature. Overall, yttrium chromite with ~20% calcium on the A-site and optimum amounts of cobalt, nickel, and/or copper on the B-site appears to be a promising candidate for interconnect applications in high-temperature SOFCs.

SECA Core R&D – Seals

New Viscous Glass Sealants May Improve SOFC Stack Lifetime. Alfred University has identified two new glass composition regimes that show promise for improved viscous glass SOFC sealants. Initial glass sealant candidates in the galliosilicate and germanosilicate compositions show promising behavior for sealing to YSZ and stainless steels in SOFC stacks. Optimized galliosilicate glasses exhibit desirable viscosity behavior, allowing seal formation at 850°C. Optimized germanosilicate compositions can form seals near 650°C with minimal alkali content, and retain a large amorphous content even after running at 850°C for 150 hours. The germanosilicate glasses are rather fluid at 850°C, yet some compositions still exhibit minimal interaction with YSZ after 1,500 hours, and thus show promise as the next-generation SOFC sealant.

Viscous Sealing Glass Successfully Identified for SOFCs. MO-SCI Corporation successfully identified and tested several glass compositions that could be used as viscous seals for SOFCs. The glasses possess desirable viscosity characteristics; that is, they have softening points in the temperature range expected for SOFC operations (650-850°C), and so cracks that might form in the glass upon thermal cycling should be closed upon reheating through a 'viscous healing' mechanism. The new glasses have relatively low liquidous temperatures (<800°C) and so do not exhibit significant crystallization when held at SOFC operating temperatures. Excessive crystallization will change the viscosity behavior and may jeopardize the viscous healing characteristics of the seal. The new glasses wet both aluminized SS441 and NiO/YSZ substrates, forming hermetic seals that have survived, in one case, >2,000-hour thermal cycles between room temperature and 750°C.

Innovative Self-Repairable Seals for SOFCs Developed. A functioning SOFC requires high-temperature seals that prevent the mixing of fuel and oxidant streams as well as prevent reactant escape to the surrounding environment. A novel in situ self-healing sealing glass concept has been advanced by the University of Cincinnati. Glasses were fabricated and characterized, and seal testing was completed to demonstrate in situ self-repair capability of the glass seals. Seal tests displayed excellent seal performance, including in situ self-repair of cracked/leaking seals. The self-healing concept requires glasses with low viscosity at the SOFC operating temperature of 800°C, but this requirement may lead to excessive flow of the glass under load in areas forming the seal. To address this challenge, a modification to glass properties such as creep via addition of particulate fillers is being pursued in the current project. The underlying idea is that non-reactive ceramic particulate filler is expected to form glass-ceramic composite and increase the glass transition/glass softening temperatures and seal viscosity, thereby increasing the creep resistance of the glass-composite seals under load. In addition, the incorporation of an appropriate filler can affect the coefficient of thermal expansion of the glass-ceramic, providing additional flexibility for developing sealing glasses that reduce mismatch stresses and improve seal reliability. Filler materials have been successfully identified, and the glass-ceramic composites that have been fabricated are expected to help in meeting DOE cost and performance goals.

SECA Core R&D – Cross-Cutting Materials and Manufacturing

Manufacturing Analysis of SOFC Components Shows Low-Cost Paths Provide Excellent Performance. For SOFCs to become economically viable, low-cost and effective manufacturing processes are essential. NexTech Materials has demonstrated that protective coatings for the metallic components in an SOFC stack can be applied by low-cost, easily scaled processes. The project has found that aerosol spray deposition (ASD) of ceramic coatings on metal SOFC interconnects provides impressive corrosion resistance and compelling process economics. ASD coatings significantly exceed the performance requirements of the SOFCs, offering stable area-specific resistance values as low as 4-7 $m\Omega\text{-}cm^2$ after 1,000 hours of operation at 800°C in wet air, with repeated thermal cycling. The cost of ASD-coated large (625 cm^2) interconnects is projected to be within DOE targets, at a cost of less than $2/part. These promising results have already led to ongoing evaluations with SOFC integrators.

Effect of Long-Term Exposure on Phase Stability of Candidate Glass Seal Materials Determined. In FY 2010, the Oak Ridge National Laboratory (ORNL) SECA team successfully characterized the microstructural changes in candidate glass seal materials after 5,000 hours aging at 800°C in air and steam+H_2+N_2 environments. Devitrification kinetics, surface phase evolution, pore size distribution, and glass transition temperature were characterized as a function of long-term SOFC environment exposure. The effect of SOFC environment exposure on the physical and mechanical properties of 8 mol% YSZ electrolytes was characterized. In addition to the environmental exposure studies, the ORNL team completed a study that determined the uncertainty associated with the quantitative chemical compositional analysis of glass seal materials. ORNL supported the SECA industrial teams in the characterization of potential glass seal materials.

SECA Core R&D – Fuel Processing

Low-Temperature Plasma and Radio-Frequency Electromagnetic Fields Investigated for Enhanced Catalytic Activity in Fuel Reformers. Two novel fuel reforming technologies have been investigated at the National Energy Technology Laboratory (NETL) to improve the quality and yields of syngas for fuel cells: enhanced catalysis via radio-frequency (RF) electromagnetic fields and low-temperature plasma-assisted reforming. Two individual systems were successfully designed and incorporated into NETL's catalyst and fuel processing units. Proof-of-concept trials were performed, and both technologies showed promising results for improving syngas yields and reducing unwanted byproduct formation (coke, olefin compounds). Specifically, the low-temperature plasma system demonstrated energy conversion efficiencies (from fuel to products) as high as 83%, with 50% conversion of fuel directly to syngas (H_2 and CO only) and 33% preserved in the form of light hydrocarbons (mostly CH_4) with little or no evidence of coking. Further testing is in progress to repeat initial results, quantify by-product reduction levels with greater accuracy, and find optimal operating conditions, such as RF and plasma operating frequencies and power levels. A synergistic relationship between these advanced technologies and traditional metal-based catalysis has been identified, and future work will include efforts to understand the underlying physical mechanisms responsible for enhanced reforming.

Molten Catalytic Coal Reactor Constructed to Produce High-Methane Content Syngas. One goal of research at the National Energy Technology Laboratory (NETL) is to generate a high methane content syngas via the steam gasification of coal with molten alkali salts as catalysts. The high methane content syngas is an ideal fuel for generating electricity in an SOFC because it significantly reduces the parasitic cooling loads of the SOFC. The integration of a molten catalytic gasifier or a fluidized bed catalytic gasifier with a SOFC is one of only a few ways to reach an overall electrical efficiency of 60% while allowing the co-production of hydrogen and/or methane during times of off-peak electricity demand. The goal of NETL's research is to expand the operating range of molten catalytic gasifiers by lowering the temperature with mixed alkali salts and lowering the pressure so as to improve integration with SOFCs that operate at or just above atmospheric pressures. NETL has successfully constructed a new molten catalytic reactor system and has begun baseline testing of the system. Construction and baseline testing of the reactor system will now allow for experiments to begin to determine the kinetics of molten salt steam-gasification and to determine the methane composition of the gas that would power a SOFC.

Diesel Reformer Operation Demonstrated for Water Neutrality. Precision Combustion, Inc. (PCI) has successfully demonstrated diesel autothermal reforming (ATR) operation under a water-neutral condition using both direct anode recycle approach and condensation approach for recovering exhaust water. The operating conditions of the proposed water recovery approaches have been optimized, and the reactor performance has been extensively characterized and evaluated. A durability test was performed to demonstrate stable catalyst performance under water-neutral conditions when operating the diesel reformer using simulated anode exhaust mixture. For the condensation approach, test results showed that a sufficient amount of water can be recovered to allow for Microlith®-based fuel reformer operation under a water-neutral condition at ambient temperatures as high as 50°C. PCI has also successfully developed a low-pressure-drop nozzle that operates with Tier II diesel. This result is significant because it reduces parasitic power requirements of the auxiliary power unit system while providing more uniform flow over a wide operating range. Finally, alternative catalysts were evaluated in order to develop a highly selective, sulfur-tolerant multifunctional reforming catalyst for fuel reformation at low cost. Results from preliminary catalyst testing demonstrated potential for a reduced-cost, highly efficient reformer system that can accomplish complete fuel conversion and ~85% reforming efficiency.

SECA Core R&D – Modeling and Simulation

Model Predicts Cathode Contact Materials Densification. Pacific Northwest National Laboratory has developed modeling tools to evaluate the effects of material volumetric changes during SOFC stack assembly on load distribution and component stresses. Volumetric changes (resulting from processes such as contact material sintering, glass-ceramic seal devitrification, and anode reduction) are important to determine residual stresses in the cells and their effect on reliability. The constitutive model was used with existing dilatometric measurements to simulate actual cathode contact materials currently under development and evaluate the sensitivity of final density to temperature, processing time, initial grain size, remote loading, layer thickness, and mechanical constraint. The model predicted that useful densification greater than 90% is possible based on the experimental data for low-temperature sintering, but sufficient strength is still required to accommodate high residual stresses up to 15 MPa.

Capability Stack Simulation Tools Enhanced. The existing SOFC-MP (Solid Oxide Fuel Cell – Multi-Physics) tools developed by Pacific Northwest National Laboratory were significantly updated to add new capabilities. For the three-dimensional stack modeling tool, memory usage was improved such that 50-cell stacks can be solved on a 64-bit Linux platform. For the two-dimensional stack modeling tool, numerous improvements were made to increase accuracy, usability, efficiency, and capability. Enhancements include simulation of mixed fuels, user-defined methane reforming rates, user-defined electrochemistry routines, simulation on targeted average current density or fuel utilization, simulation of stack current-voltage curve, and cell-to-cell variations on geometry and fuel/oxidant properties. This modeling tool was successfully validated against literature benchmarks for several single-cell cases and a 5-cell stack. Results for multi-cell stacks with more than 100 cells and cell-to-cell variations possible in tall stack experiments were also demonstrated.

SECA Core R&D – Balance of Plant

Hybrid Heat Exchanger Successfully Demonstrated for SOFC Generators. Acumentrics Corporation, in conjunction with Blasch Precision Ceramics, has successfully integrated a ceramic monolith into a combination cross-flow ceramic and counter-flow metallic cathode air recuperator. This arrangement takes advantage of a high-temperature, near-net-shape cast cross-flow ceramic core, while enabling the use of lower-grade metallic alloys in the medium-to-low temperature counter-flow metallic section. The hybrid recuperator is capable of meeting the >80% effectiveness required in residential- and commercial-scale solid oxide fuel generators. The robustness of the design was demonstrated through duration and thermal cycle testing.

Efficient Low-Cost Blower Being Developed for 3 to 10 kW SOFC Systems. R&D Dynamics Corporation is developing a low-cost cathode air blower which will cost less than $100 at a production volume of 50,000 units per year. The blower being developed is efficient, reliable, oil-free, maintenance-free, and compact. Design for Manufacturing and Assembly techniques were used to reduce the cost of the blower. The blower was designed with only 17 parts. The blower was detail designed, and a prototype unit was manufactured. A low-cost controller was developed and tested for the blower. The prototype unit was tested, and performance data were collected. The blower is further optimized for performance improvements. The low-cost and efficient blower will help DOE meet its cost target goals for small SOFC systems.

Innovative Concepts

Low Degradation, High Performance of LSCF-Based SOFCs Successfully Demonstrated. GE Global Research has made significant progress in mitigating performance degradation of lanthanum strontium cobalt ferrite (LSCF)-based SOFCs. A high-performance LSCF-based cathode architecture and processing route was demonstrated to have no measurable performance degradation over 1,000 hours at 800°C measured at 0.7 V using a gold cathode current collector. Subsequent test results using 441HP ferritic stainless steel current collectors with protective spinel coatings, operating at ~1 W/cm^2, yielded a 1.9%/1,000 hr power density degradation rate that decreased with time and approached an asymptotic value over the 1,500-hour test. The observed resistance increase was purely ohmic, with no loss in catalytic activity. Further, the resistance change could be directly attributed to the resistance associated with the anticipated growth of chromium oxide on the stainless steel current collector.

NexTech Demonstrates Advanced Electrolyte-Supported Planar SOFCs. NexTech Materials is validating an advanced planar SOFC design for megawatt-scale power generation systems. This design, termed the *FlexCell*, offers intrinsic scalability to large areas, as well as other important attributes that translate to high performance and efficiency. The overall goal of the project is to demonstrate these promising attributes with electrolyte-supported *FlexCells* made with YSZ. In Phase I, NexTech demonstrated that high performance can be achieved with YSZ-based *FlexCells* and scaled the fabrication of YSZ-based *FlexCells* to 500-cm^2 areas. A manufacturing cost analysis confirmed that full-scale (250 MW) production costs of *FlexCells* will be less than $50/kW, and NexTech identified paths to reduce costs to less than $40/kW. In collaboration with The Ohio State University, a finite element analysis model of mechanical robustness was established, which has been applied to the design of large-area (500-cm^2 area) *FlexCells* for fabrication and testing in Phase II of the project.

Advanced Research

Direct Reduction of Tin Oxide with Coal Successfully Investigated. In support of the liquid tin anode fuel cell (LTAFC) research at the National Energy Technology Laboratory, a series of direct reduction tests with coal was conducted on samples of pure tin oxide. These tests successfully determined reduction efficiencies at the fuel cell operating temperature, and the fate of contaminants supplied by the coal ash component. Results have demonstrated that reduction efficiencies of approximately 90% or greater can be achieved for both eastern and western coals at 1,000°C, while virtually all critical contaminants report to the slag component at a mass distribution of 90% or higher. This trend is independent of the coal used and suggests that effective slag cleaning of these contaminants is possible. Future work will investigate direct reduction with coal of a dilute tin oxide component within a molten tin bath, to better simulate the LTAFC environment.

Oxygen Transport Measurements Improved in Molten Metal Anodes. National Energy Technology Laboratory researchers have completed spatial thermal probing and observed isothermal conditions within the liquid tin anode of an SOFC. Equipment was designed and constructed to facilitate independent positioning of sensors to allow direct measurement of spatial gradients in temperature and potential within the liquid tin. With these upgrades, the researchers have been able to confirm that thermally induced convection is not affecting oxygen diffusion measurements. The recent upgrades have also facilitated measurement of oxygen diffusion within the molten tin, showing values that approach those reported in the literature. Researchers have used the new equipment to probe the spatial variations in potential within the tin while investigating the recent observation of enhanced effective oxygen diffusion in the presence of hydrogen fuel. Researchers speculate that the improvement in the effective oxygen diffusion rate is attributable to modest hydrogen transport into the tin, which could extend the tin/fuel reaction layer into the tin bulk and consequently enhance the cell performance. Through better understanding of oxygen transport within the liquid tin anode, improvements to direct carbon conversion efficiencies of SOFCs may be possible.

Navy Evaluates SECA Fuel Cells for Undersea Vehicle Application. The Naval Undersea Warfare Center, Division Newport (NUWCDIVNPT) is collaborating with DOE to examine the effect of pure oxygen on SOFC stacks and to provide proof-of-concept system demonstrations. NUWCDIVNPT's role is to provide independent testing and evaluation of SOFC stacks being developed under the DOE's SECA program.

System demonstrations have consisted of an SOFC stack integrated with fuel processor, high-temperature anode recycle blower, and carbon dioxide sorbent. This system has attained an overall fuel utilization over 75%, oxygen utilization over 95%, and fuel efficiency over 50% lower heating value. These pure oxygen studies have shown up to 10% efficiency gains by using pure oxygen instead of air, and SOFCs show promise for use in undersea vehicles and other spin-off applications.

SECA Adds SBIR Projects

Several new Phase I projects were selected in 2010 under an SBIR solicitation. TDA Research will assess a post-SOFC residual fuel oxidizer for carbon capture, NexTech Materials will perform a comprehensive manufacturing cost analysis of volume manufacturing of SOFC stacks, and CellTech Power will assess the direct utilization of coal in a liquid tin anode SOFC.

2010 Annual SECA Workshop in Pittsburgh, Pennsylvania

The SECA program held its 11th annual workshop July 27–29, 2010, in Pittsburgh, Pennsylvania. Principal investigators of projects made up-to-date presentations. The findings and recommendations will be used by DOE to guide future work and by to make programmatic and funding decisions for the upcoming fiscal years. The workshop proceedings can be found on the program's website at http://www.netl.doe.gov/seca/.

Summary

SECA will meet its final cost goal of $175/kW stacks by the end of 2010. Ongoing cell performance and scaling improvements will undoubtedly result in additional cost reduction and the testing of larger SOFC stacks. Technological spinoffs of SOFCs into a variety of other applications, especially APUs for heavy-duty trucks, related military power applications for the Department of Defense, and potential manned space craft applications for the National Aeronautics and Space Administration will add to market penetration, increase manufacturing production volume, and lower SOFC cost.

By developing fuel cells to operate cost effectively on coal gas as well as natural gas, bio-fuels, diesel, and hydrogen, SECA is solving today's environmental, climate change, fuel availability, and energy security issues. SECA fuel cells are ideal for use in central generation applications, enabling high efficiency, diverse opportunities for carbon capture (e.g., post-power block), lower criteria pollutant emissions (e.g., less than 0.5 ppm NOx, regardless of fuel), and water conservation. IGFC system configurations utilizing near-term gasification and syngas cleaning technologies will generate power from coal with overall efficiencies of 50 percent (HHV, coal to AC power), including the coal gasification and carbon capture processes. Advanced systems are capable of efficiencies of 60 percent. In conjunction with SECA-driven fuel cell cost reduction, these IGFC systems will enable the clean, efficient and cost-effective use of the nation's most abundant fossil fuel. The once distant vision of using clean, low-cost fuel cell technology for everyday applications is now within reach.