Executive Summary

SECA Program Overview

The U.S. Department of Energy (DOE) Office of Fossil Energy, through the National Energy Technology Laboratory (NETL) and in collaboration with the Pacific Northwest National Laboratory, is forging government/industry partnerships under the Solid State Energy Conversion Alliance (SECA) to reduce the cost of fuel cells and to develop fuel cell coal-based systems for clean and efficient central power generation. These goals equate to removing environmental and climate change concerns associated with fossil fuel use while simultaneously establishing a foundation for a hydrogen-based economy and a secure energy future in the United States. With the successful completion of the first cost reduction phase in fiscal year (FY) 2006, SECA is one step closer to realizing its vision of cost-effective, near-zero-emission fuel cell technology for commercial applications.

Launched in 2000, SECA is an inventive collaboration among government, the private sector and the scientific community to accelerate the development of modular, low-cost, fuel-flexible solid oxide fuel cell (SOFC) systems that can operate on coal gas, natural gas, bio-fuels, diesel fuel and hydrogen. This approach will facilitate deployment into the marketplace by emphasizing cost competitiveness with established technologies while taking advantage of existing fuel distribution infrastructures. SECA's DOE mission is to have its fuel cell systems ready for FutureGen, soon to be the world's cleanest coal-fueled power plant.

The Administration's Office of Management and Budget recently cited the Solid State Energy Conversion Alliance (SECA) program as leading the way in Government-industry partnerships:

"The SECA program leverages private-sector ingenuity by providing Government funding to Industry Teams developing fuel cells, as long as the Teams continue to exceed a series of stringent technical performance hurdles. This novel incentive structure has generated a high level of competition between the Teams and an impressive array of technical approaches. The SECA program also develops certain core technologies that can be used by all the Industry Teams to avoid duplication of effort. The program exceeded its 2005 performance targets, and it is on track to meet its goal for an economically competitive technology by 2010."

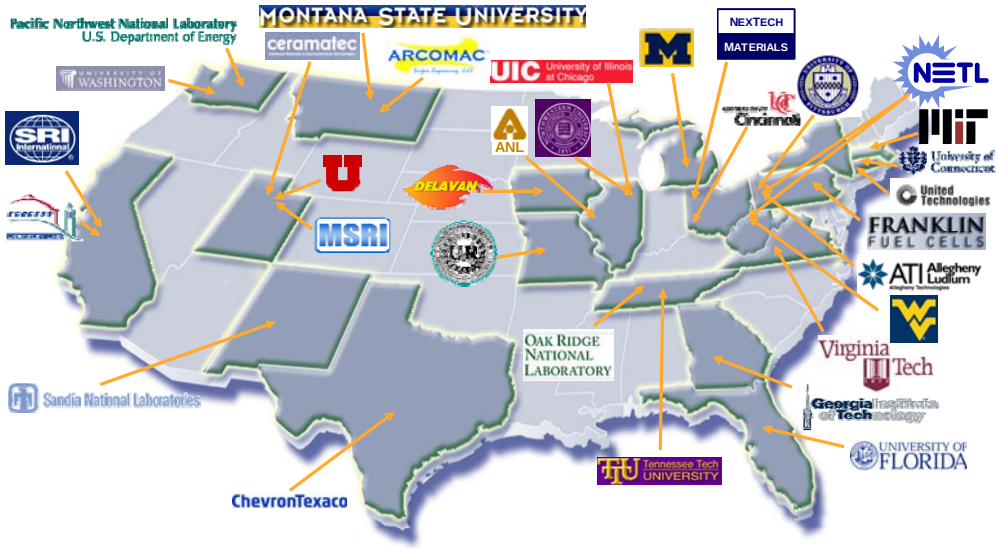
The SECA Cost Reduction goal is to develop and design SOFCs capable of manufacture at $400 per kilowatt (kW) by 2010. Concurrently, SECA Coal-Based Systems will scale and integrate SECA SOFC technology for delivery to FutureGen in 2011. Development of large (greater than 100 megawatts) SOFC power blocks will enable affordable, efficient, and environmentally-friendly electrical power from coal. Key system capabilities to be proven by 2015 include 50 percent or greater IGCC plant efficiency in

converting the energy contained in coal (HHV) to grid electrical power; the capture of 90 percent or more of the carbon contained in the coal fuel (as CO_2); reduction of NO_x to levels well below those of environmental concern; and a cost of $400/kW for the fuel cell power block, exclusive of the coal gasification unit and CO_2 separation subsystems.

The alliance is comprised of three groups: Industry Teams, Core Technology program participants, and federal government management. The Industry Teams design the fuel cells and handle most hardware and market penetration issues. The Core Technology program is made up of universities, national laboratories, small businesses, and other R&D organizations and 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 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 work together to provide vital R&D and testing in support to the Industry Teams.

SECA Core Technology & Advanced Research Participants



In the same spirit of healthy competition, the Industry Teams leverage the collective ingenuity of the Core Technology participants 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.

SECA Cost Reduction: To achieve cost targets, Industry Teams are engaged in refining and validating advanced SOFC technologies in 3-10 kW modules that can be mass produced, aggregated, and scaled to meet a broad range of applications. This development 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. It also requires reaching a full spectrum of large markets, such as auxiliary power units (APUs) for trucks and recreational vehicles – by providing on-board power while the vehicle engine is off, SOFC-based APUs address the challenges of anti-idling legislation enacted in many states and at the same time establishes capacity to reduce cost to enable delivery of large SECA systems to FutureGen and the new breed of coal plants that follow. Additional markets include residential-commercial-industrial power, a wide range of distributed generation, and specialized applications for the military. Producing a common module for these vast markets will create the opportunity for the high-volume production required to reduce cost to the necessary level.

SECA R&D: The Core Technology program provides comprehensive applied research support in five focus areas. This structure and the provisions in place reduce cost by leveraging resources so that all Industry Teams do not engage in separate applied research programs paying multiple times for the same research done once in the Core program. This approach also ensures that only major issues are addressed. SECA R&D's goal is to raise the technology bar in large strides rather than small steps. Core program areas are also funded by special topics within the Science Initiatives, Small Business Innovative Research, Basic Energy Sciences, University Coal Research, and Historically Black Colleges and Universities programs. The Core Technology focus areas include the following:

- Materials and Manufacturing – Research focuses on improved reliability, improved performance, ability to tolerate any fuel or air contaminants, and reduce cost;
- Fuel Processing – Develop fuel processing technologies that will meet application requirements such as zero water, space and volume, and transient capability;
- Power Electronics – Optimizes fuel cell power system efficiency and cost in conversion of fuel cell output to usable DC (direct current) and AC (alternating current) power;
- Modeling and Simulation – Creates design models to determine a reliable operating space and guide manufacturing; and
- Balance of Plant – Focuses on high temperature heat exchangers and blowers to enable achieving high efficiency, low cost, and a simple system.

SECA Fuel Cell Coal-Based Systems: To address the issue of scalability and incorporation into IGCC plants, DOE integrated the SECA Cost Reduction activities with the SECA Coal-Based Systems program. The goal of this program element is to develop and demonstrate the fuel cell technology required for central power stations and provide a power block to FutureGen. It leverages the advances made in SOFC cost reduction and technology under the SECA program by extending that technology to large central power generation. Three Industry Teams will transition their SECA Cost Reduction projects into SECA Coal-Based Systems projects and develop systems for fuel cell incorporation into an IGCC plant. All SECA Industry Teams will continue SECA cost reduction activities through 2010 with the best fuel cell stacks available for delivery to FutureGen. 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 in preparation for operation at FutureGen.

Fuel Cell Systems: The Hybrids program has provided research advances in fuel cell systems by linking technologies in a common system to generate electricity from coal syngas at high efficiencies. Power systems that contain a combination of high-temperature fuel cells and integrated heat engines (e.g., gas turbines, steam generators, and Stirling engines) have the potential for ultrahigh efficiency in converting fossil fuels to electricity. The total efficiency of a hybrid system can in principle be raised to greater than 70 percent (55% demonstrated in small size), while NOx emissions are essentially eliminated. Carbon dioxide reduction is facilitated through increased efficiency and capture. The inherent ability to keep the fuel and air streams of the fuel cell separated while producing power makes carbon capture a particularly simple process.

Advanced Research: The High Temperature Electrochemistry Center (HiTEC) was formed in 2004 to provide crosscutting, multidisciplinary research that leads to advanced electrochemical technologies minimizing the environmental consequences of using fossil fuels in energy generation. HiTEC 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 beyond what can be accomplished in the next five to ten years.

FY 2006 Key Program Accomplishments

SECA Cost Reduction: The Power of a Goal

The SECA program's Industry Teams are hard at work on the design and manufacture of a variety of low-cost fuel cell prototypes. Recent testing of these prototypes has demonstrated giant leaps made toward fuel cell commercialization. Manufactured with a scalable mass-production technique, these SOFC prototypes have exceeded all of SECA's Phase I targets for availability, efficiency, endurance, and cost. Representative data include an availability of 90 percent, over and above the SECA Phase I target of 80 percent, and an efficiency of 41 percent in a 5.4 kW system, surpassing the first SECA target of 35 percent. The demonstrated superior efficiency in this small size confirms the

ability to achieve much higher efficiencies in larger systems. And most significant of all, the $746/kW system cost is well on its way to $400/kW by 2010.

2006 Annual SECA Workshop and Peer Review Held in Philadelphia, Pennsylvania

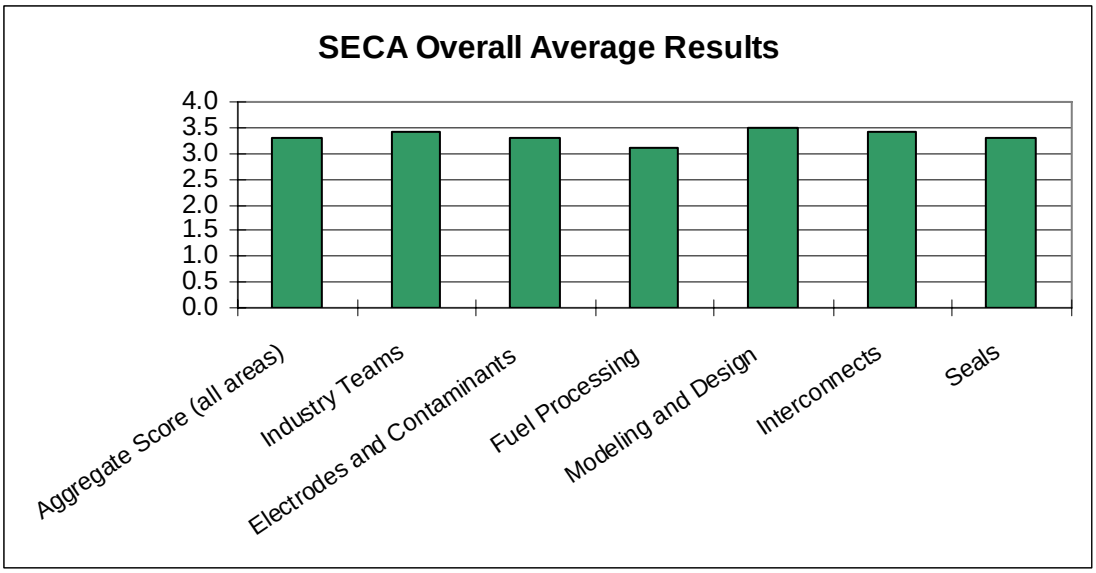
The SECA program held its 7th Annual SECA Workshop and Peer Review, September 12-14, 2006, in Philadelphia, Pennsylvania. Principal Investigators of 24 projects provided presentations, plus there were two additional related presentations. A panel of independent technical experts covering all aspects of fuel cell technologies conducted peer reviews of all the presented projects. The findings and recommendations of the peer reviewers will be used by the project managers to guide their future work and by the Technology Development Manager at DOE to make programmatic and funding decisions for the upcoming fiscal years. This report summarizes the comments from the Peer Review Panel at the workshop. The work evaluated in this document supports the Strategic Management System requirements of the DOE Under Secretary for Energy, Science & Environment with respect to Peer Reviews of the Office of Fossil Energy R&D programs, as documented in the Protocol for the Conduct of Fossil Energy Peer Reviews.

Summary of Peer Review Results

A total of 14 panel members participated in the peer review process. A total of 24 out of over 40 active SECA projects were reviewed at the meeting. For a summary of all of these projects, please refer to the 2006 Office of Fossil Energy Fuel Cell Program Annual Report, which can be found on the NETL website (http://www.netl.doe.gov). This report is also available on CD upon request at the NETL website.

DOE SECA program and project management have reviewed all positive comments and all suggested improvements for consideration in future program and project planning.

The SECA projects reviewed were highly praised by the reviewers. The following graph summarizes the overall results of the 2006 SECA Peer Review. The graph depicts the weighted average scoring results of the four evaluation criteria (relevance, approach, technical accomplishments, and future research) for each technology area compared with the aggregate score of 3.3 for all technology areas. The scores ranged between good and outstanding, indicative of program effectiveness.



Scoring: 1=poor, 2=fair, 3=good, 4=outstanding

Following are DOE analysis of reviewer comments in each technology area.

DOE Analysis of Reviewer Comments

Industry Teams:

The reviewers provided the following positive feedback for the Industry Teams projects:

- Industry Teams have developed prototypes, tested these prototypes under real conditions, and met the SECA Phase I metrics.
- The Industry Teams have a strong product orientation. They understand their markets and are designing their SOFCs accordingly.
- The focus on large-scale coal-fueled power generation systems is an important progression for the SECA fuel cell program. The Industry Teams have proposed very feasible approaches to achieve their goals for coal-fueled power generation using technology developed in SECA cost reduction to full advantage.
- The focus on cell and stack scale-up and improved manufacturing techniques is appropriate and necessary.

Suggestions for improvement include greater teaming of some Industry Teams with Core Technology Program participants and more focus on improving fuel processing for auxiliary power applications.

Electrode and Contaminant Issues:

The reviewers provided the following positive feedback for the electrode and contaminant projects:

- Research on electrodes and contaminants is of critical importance to achieving the SECA cost and performance targets for solid oxide fuel cells.
- The electrodes and contaminants projects have feasible technical approaches and are making progress toward accomplishing their goals.
- These projects are greatly advancing the understanding of mechanisms that affect performance.
- Cathode infiltration has been shown to have fundamental advantages over other techniques, particularly from a manufacturing perspective.
- Investigations of chromium poisoning and the effects of coal contaminants are particularly important activities, and these projects are making good progress.

Suggestions for improvement included beginning long-term testing immediately; focusing the research on a specified set of issues; and obtaining extensive, detailed data. Reviewers also stressed the importance of understanding mechanisms affecting electrode performance. Reviewers recommend that work on chromium poisoning and coal contaminants continue and that future cathode work focus on degradation and stability.

Fuel Processing:

The reviewers provided the following positive feedback for the fuel processing projects:

- The fuel processing projects are essential to enabling the SECA goal of $400/kW.
- An effective approach being used, starting with fundamental principles to identify the best catalysts or processes and how they are best employed in fuel processors.
- Testing fuels with “real-world” sulfur levels to evaluate the impact sulfur has on fuel processor performance is appropriate and necessary.
- The slate of research projects, current & future, is headed in the right direction.

Suggestions for improvement included conducting long-term testing starting immediately and accelerating technology development efforts to meet the commercialization schedules of the Industry Teams.

Modeling and Design:

The reviewers provided the following positive feedback for the modeling and design projects:

- Good stack design tools and comprehensive material property data are important to the SOFC stack R&D efforts of the SECA Industry Teams.
- Excellent progress has been made in developing the modeling as well as obtaining the key thermal-mechanical properties.
- The program includes a good blend of experiment and modeling.

Reviewers recommended that system integration models should provide component requirements for BOP and power electronics suppliers, and longer-term testing is needed at both steady-state and transient SOFC conditions to determine stability of microstructures.

Interconnects:

The reviewers provided the following positive feedback for the interconnects projects:

- The interconnects projects are progressing in the right direction, and the results indicate that viable approaches are being pursued.
- Excellent technical progress is being delivered as a result of the industrial experience and strong engineering capability of the performers.
- Projects provided good long-term, repeatable data with promising results, which were well-executed and well-thought through experiments.
- The Mn-Co spinel coating has proven to be effective in lowering the area-specific resistance (ASR) of metal interconnects.
- Surface treatment by RE elements is an effective way of preventing scale growth during operation and spalling upon thermal cycling, enabling the use of low Cr ferritic steel.

Recommendations on improving the projects consisted of exploring different coating compositions in the MnO space. Scope additions consisted of (1) coating process improvement, (2) coating process cost analysis, (3) electrochemical on-cell testing, (4) parametric stack testing, (5) long-term effectiveness of the coating addressed in stack operating conditions, (6) surface treatment process cost analysis, and (7) alternative compositions (La, Y or combination of REs) in surface treatment. In general, the reviewers recommended that the level of effort directed toward reducing alloy cost be increased, that data be acquired on ASR and long-term durability, and that projects focus on converting promising research into engineering solutions.

Seals:

The reviewers provided the following positive feedback for the seals projects:

- The seals projects achieved good progress on multiple technologies and showed potential seal solutions.

The recommendations for future work activities for seals projects were focused on long-term testing. The effect of seal systems on performance stability needs to be established with long-term tests. Composition and morphology changes need to be monitored for changes over time under typical fuel cell operating conditions when exposed to high temperatures. The stability of strength and electrical properties of seal systems need to be evaluated to assure that the seals have long-term durability commensurate with SOFC lifetimes.