Final Report
Strategic Center for Coal Fuel Cell Program 2008 Peer Review Meeting

MEETING SUMMARY AND RECOMMENDATIONS REPORT

Pittsburgh, Pennsylvania
April 21 – April 25, 2008

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

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FINAL REPORT
2008 STRATEGIC CENTER FOR COAL FUEL CELL PROGRAM PEER REVIEW MEETING

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José D. Figueroa
NETL Project Manager and Meeting Coordinator
(412) 386-4966

Meeting Host Organization

Technology & Management Services, Inc.
Steven T. Ostheim
(412) 386-6485

Review Panel

AMERICAN SOCIETY OF MECHANICAL ENGINEERS
Minking K. Chyu, Chair, Peer Review Panel
Richard Laudenat, Chair, Peer Review Executive Committee
Michael Tinkleman, Director, Research
ASME Center for Research and Technology Development
(202) 785-7394

Meeting Facilitator and Final Report

Ross Brindle, Energetics Incorporated
(410) 953-6239

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DISCLAIMER

The work performed on this task/subtask was completed under Technology & Management Services, Inc. (TMS), Prime Contract DE-AC26-05NT41816 (Subtask 305.01.02.3) for the DOE NETL. To assist in the performance of this subtask, TMS has subcontracted with ASME.

MEETING SUMMARY AND RECOMMENDATIONS REPORT

EXECUTIVE SUMMARY

The mission of the U.S. Department of Energy's (DOE) Office of Clean Coal (OCC) is to ensure the availability of ultra-clean, abundant, low-cost, domestic energy from coal to fuel economic prosperity, strengthen energy security, and enhance environmental quality. To achieve its mission, the Office of Clean Coal is organized into eight technology programs and an international support program. One of these eight technology programs, administered by the DOE Office of Fossil Energy's National Energy Technology Laboratory (NETL), is the Solid State Energy Conversion Alliance (SECA) Fuel Cell Program. The objectives of the Fuel Cell Program are to ensure energy security through the generation of efficient, cost-effective electricity from coal with near-zero atmospheric emissions, including carbon, in central station applications. The objectives also include providing the technology base to permit grid-independent distributed generation applications.

The Office of Fossil Energy sponsored and National Energy Technology Laboratory managed SECA program has made substantial contributions and progress to making fuel cells available for virtually any stationary application on fossil fuels. The SECA program is focused on the end goal of deploying fuel cells in near zero emission coal plants with greatly reduced water requirements and capable of capturing 99% of carbon at costs not exceeding a typical cost of electricity available today. This is the end goal for two reasons; this is by far the largest market with the largest positive national impact; historically federal funding has focused on game changing technology with risks higher than the private sector initially can accept on their own. The current SECA progress indicates that commercial ready stacks, which are the power producing part of a fuel cell system, will be ready in 2010. This will be followed by MW demos in 2012 and 5 MW demos with integrated turbines in 2015. By 2017 the MW demos will have five-years operating experience and the 5MW's will have demonstrated the integration of fuel cell and heat recovery (turbines) sufficiently to warrant sponsoring a Clean Coal Power Initiative resulting in a 250 - 500 MW Integrated Gasification Fuel Cell system in 2020. This is a very similar commercialization path demonstrated by the joint private/public partnership that started the nuclear industry with the construction of the Shippingport Atomic Power Station in Pittsburgh, PA. In parallel, commercial applications with smaller risk not requiring this level of government support will use SECA fuel cell technology in the many other stationary applications requiring efficient and low cost power including those that can use Combined Heat and Power such as Industrial applications. Two such applications are currently under development in other DOE and DOD Offices; these include auxiliary power units for trucks that will reduce overnight truck idling emissions and power sources for Unmanned Underwater Vehicles.

In compliance with the President's Management Agenda for "Better Research and Development Investment Criteria" and subsequent requirements from the Office of Management and Budget (OMB), DOE and NETL are fully committed to improving the quality of research projects in their programs. To aid this effort, DOE and NETL conducted a 2008 Fuel Cell Program Peer Review Meeting with independent, technical experts to assess ongoing research projects and, where applicable, to make recommendations for improvement.

In cooperation with Technology & Management Services Inc., the American Society of Mechanical Engineers (ASME) convened a panel of nine leading government, academic, and industry experts on April 21-25, 2008, to conduct a five-day peer review of selected Fuel Cell Program research projects supported by NETL.

Overview of Office of Fossil Energy Fuel Cell Program Research Funding

The total value of these 18 projects, over the duration of the project period, is $270,493,464. Of this amount, $163,240,257 (60%) comes from DOE and the remaining $107,253,207 (40%) comes from project partner cost sharing.

The 18 projects that were the subject of this peer review are summarized in Table ES-1 and in Section II of this report.

TABLE ES-1 FUEL CELL PROGRAM PROJECTS REVIEWED

Reference Number	Project No.	Title	Lead Organization	Principal Investigator	Total Funding[A]		Project Duration	
					DOE	Cost Share	From	To
01	NT41837	Coal-Based Solid-Oxide Fuel Cell Power Plant Development	FuelCell Energy, Inc.	Jody D. Doyon	$35,499,993	$23,661,194	27-Feb-04	30-Sep-08
02	NT41246	Solid State Energy Conversion Alliance	Delphi Automotive Systems	Steven R. Shaffer	$76,926,801	$66,810,929	1-Jul-02	31-Dec-11
03	NT42812	Santa Clara County California Solid-Oxide Fuel Cell Project	Santa Clara County California	Caroline Judy	$1,383,826	$1,383,826	15-Aug-06	15-Aug-09
04	NT42613	Coal-Gas-Fueled SOFC Hybrid Power Systems with CO_2 Separation	Siemens Power Generation - Pittsburgh	Joseph F. Pierre	$25,999,831	$8,600,282	1-Oct-05	30-Sep-08
05	NT42810	Solid-Oxide Fuel Cell Technology Stationary Power Application Project (NC)	Siemens Power Generation - Pittsburgh	Joseph F. Pierre	$929,025	$988,718	6-Sep-06	30-Sep-08
06	NT42614	Solid-Oxide Fuel Cell Coal-Based Power Systems	GE Global Research	Matthew Alinger	$7,742,706	$5,015,936	26-Sep-05	31-May-08
07	NT42513	Evaluation of a Functional Interconnect System for Solid-Oxide Fuel Cells	Allegheny Technologies, Inc.	James Rakowski	$455,939	$191,591	30-Jun-05	31-Dec-08
08	FEAA066	Reliability of Materials and Components for Solid-Oxide Fuel Cells	Oak Ridge National Laboratory	Edgar Lara-Curzio	$3,400,000	$0	1-Oct-00	30-Sep-08
09	FWP40552	Low-Cost Modular SOFC Development—Refractory Glass	Pacific Northwest National Laboratory	Matt Chou[B]	$750,000	$0	1-Jun-05	30-Sep-08
10[C]	08-220621c	Coal-Based Fuel Cells—University Research Initiative Projects	NETL Office of Research and Development	Randy Gemmen	$311,000 / $257,000	$0	1-Oct-07	30-Sep-10
11	FWP49071	Solid-Oxide Fuel Cell Research and Development—Synchrotron	Argonne National Laboratory	Paul Fuoss	$810,000	$0	1-Jun-07	31-May-09
12	MSD-NETL-01	Development of Inexpensive Metal Alloy Electrodes for Cost-Competitive Solid-Oxide Fuel Cells	Lawrence Berkeley National Laboratory	Steven J. Visco	$1,950,000	$0	1-May-01	30-Sep-10
13	NT41572	Functionally Graded Cathodes for Solid-Oxide Fuel Cells	Georgia Tech Research Corporation	Meilin Liu	$900,000	$245,539	29-Sep-02	30-Mar-08
14	NT42516	Development of Sulfur- and Carbon-Tolerant Reforming Alloy Catalysts Aided by Fundamental Atomistic Insight	University of Michigan	Suljo Linic	$199,997	$81,565	1-Jul-05	31-Dec-08
15	FWP40552	Low-Cost Modular SOFC Development—Modeling	Pacific Northwest National Laboratory	Moe A. Khaleel	$1,200,000	$0	1-Jun-03	30-Sep-08
16	07-220611	Fuel Processing & Hydrogen Production	NETL Office of Research and Development	David A. Berry	$1,933,000	$0	1-Oct-06	30-Sep-08
17	08-220621a	Coal-Based Fuel Cells—Contaminant Testing	NETL Office of Research and Development	Randy Gemmen	$1,500,000	$0	1-Oct-06	30-Sep-09
18	NT41567	A Low-Cost Soft-Switched DC/DC Converter for Solid-Oxide Fuel Cells	Virginia Polytechnic Institute & St. University	Jason Lai	$1,091,139	$273,627	1-Oct-02	31-Jul-08
				TOTALS	$163,240,257	$107,253,207		

Notes: A: All funding amounts and project durations obtained from NETL.
B: Presentation was made by Jeff Stevenson.
C: This project consists of two related projects presented during one project period.

Overview of the Peer Review Process

NETL requested that ASME assemble a Peer Review Panel of recognized technical experts to provide recommendations on how to improve the performance, management, and overall results from each individual research project. In advance of the peer review meeting, each project team prepared for the Review Panel an 11-page Project Summary Sheet containing an overview of the project's purpose, objectives, and achievements. At the meeting, each research team made a 45-minute presentation (or longer, for larger projects) that was followed by a 20-minute question-and-answer session with the Reviewers and a 25-minute closed-session discussion of each project. ASME developed a set of agreed-upon review criteria to be applied to the projects under review by the Review Panel at this meeting

Based on lessons learned from prior Peer Reviews and the special circumstances associated with Fuel Cell research; both the PI presentations and Questions and Answer sessions with the ASME Review Panel for the ASME DOE Solid Oxide Fuel Cell Peer Review were held as closed sessions, limited to the ASME Review Panel and DOE/NETL personnel. This ensured frank and open discussions between the PI's and the Review Panel.

Each Panel member then individually evaluated the 18 projects based on a predetermined set of review criteria and provided written comments and recommendations. For each of the nine review criteria, the individual reviewer was asked to score the project as one of the following:

- Effective (5) - Effective projects set ambitious goals, achieve results, are well-managed and enhance the likelihood of meeting program goals and objectives.
- Moderately Effective (4) - In general, a project rated Moderately Effective has set ambitious goals and is well-managed, and is achieving results. Better results could be realized by focusing on key technical issues, more efficient use of resources, and improvements in overall management.
- Adequate (3) - Adequate describes a project that needs to set more ambitious goals, achieve better results, improve accountability or strengthen its management practices.
- Ineffective (2) - Ineffective Projects are unable to achieve results due to a lack of clarity regarding the project's purpose or goals, poor management, or some other significant weakness (e.g., technical problem).
- Results Not Demonstrated (1) - Results Not Demonstrated indicates that a project has not been able to develop acceptable performance goals or collect data to determine whether it is performing.

Figure ES-1 shows the overall average score, including all nine review criteria, for all 18 projects.

FIGURE ES-1 OVERALL SCORING AVERAGES – BY PROJECT

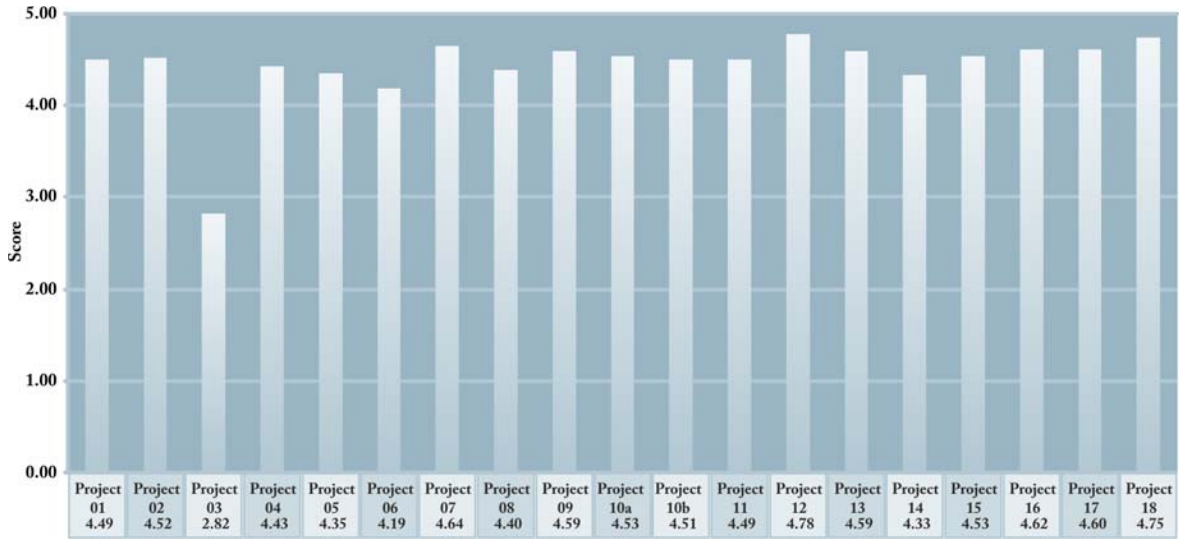


Table ES-2 shows the overall average, highest individual, and lowest individual score given for each review criterion across all 18 projects reviewed.

TABLE ES-2 SCORES BY REVIEW CRITERION

Criterion	Average	Highest	Lowest*
1. Existence of Clear, Measurable Milestones	4.7	5.0	4.6 / 3.0
2. Rate of Progress	4.6	4.9	4.3 / 3.4
3. Technical Approach	4.6	5.0	4.4 / 2.9
4. Economic Analysis	3.9	4.6	3.4 / 1.8
5. Utilization of Government Resources	4.6	5.0	3.8 / 2.6
6. Scientific and Technical Merit	4.5	4.9	4.1 / 2.5
7. Anticipated Benefits if Successful	4.5	5.0	4.2 / 3.4
8. Commercialization Potential	4.2	5.0	3.7 / 3.0
9. Possible Adverse Effects Considered	4.2	4.8	4.0 / 2.9

*To present a more accurate view of the lowest scores, two values have been given. The first value is the lowest average score of all projects except project 03: DE-FC26-06NT42812, Santa Clara County California Solid-Oxide Fuel Cell Project. The second value is the lowest average score of all projects. This distinction is made because project 03 received significantly lower scores than the other projects reviewed.

For more on the overall evaluation process and the nine review criteria, see Section III.

A summary of key project findings as they relate to individual projects can be found in Section IV of this report. Process considerations and recommendations for future project reviews are found in Section V.

For More Information

For more information concerning the contents of this report, contact the NETL Project Manager, José D. Figueroa, at (412) 386-4966 or Jose.Figueroa@netl.doe.gov.

I. INTRODUCTION

In 2008, the American Society of Mechanical Engineers (ASME) was invited to provide an independent, unbiased, and timely peer review of selected projects within the U.S. Department of Energy (DOE) Office of Fossil Energy Fuel Cell Program (a program administered by the Office of Fossil Energy's National Energy Technology Laboratory (NETL). On April 21–25, 2008, ASME convened a panel of nine leading government, academic, and industry experts to conduct a five-day peer review of selected Fuel Cell Program research projects. This Report contains a summary of the findings from that review.

Compliance with OMB Requirements

DOE, the Office of Fossil Energy, and NETL are fully committed to improving the quality and results of their projects. The peer review of selected projects within the Fuel Cell Program was designed to comply with requirements from the Office of Management and Budget (OMB) outlined in the President's Management Agenda, specifically the requirement for "Better Research and Development Investment Criteria."

Overview of the Peer Review Process

ASME was selected as the independent organization to conduct a five-day peer review of 18 Fuel Cell Program projects. ASME performed this project review work as a subcontractor to Technology & Management Services Inc. (TMS), an NETL Site Support Contractor. NETL selected the 18 projects, while ASME organized an independent Review Panel of nine leading government, academic, and industry fuel cell technology experts. Prior to the meeting, Principal Investigators (PIs) submitted an 11-page written summary (Project Summary Sheet) of their project's purpose, objectives, and progress. At the meeting, each research team made a 45-minute oral presentation (or longer, for larger projects) that was followed by a 20-minute question-and-answer session with the reviewers and a 25-minute review panel discussion of each project. Each Panel member then individually evaluated the 18 projects based on a predetermined set of review criteria and provided written comments and recommendations. This document (*Meeting Summary and Recommendations Report*), prepared by ASME, provides a general overview of findings from the Peer Review and is available to the public.

Based on lessons learned from prior Peer Reviews and the special circumstances associated with Fuel Cell research; both the PI presentations and Questions and Answer sessions with the ASME Review Panel for the ASME DOE Solid Oxide Fuel Cell Peer Review were held as closed sessions, limited to the Review Panel and DOE/NETL personnel. These sessions ensured frank and open discussions between the PI's and the Review Panel.

ASME Center for Research and Technology Development (CRTD)

All requests for peer reviews are organized under ASME's Center for Research and Technology Development (CRTD). CRTD's Director of Research, Dr. Michael Tinkleman, with advice from the chair of the ASME Board on Research and Technology Development, selects an executive committee of senior ASME members that is responsible for reviewing and selecting all review panel members and ensuring there are no conflicts of interest within the panel or the review process. In consultation with NETL, ASME was responsible for formulating the review meeting agenda, providing information advising the PIs and their colleagues on how to prepare for the review, facilitating the review session, and preparing a summary of the results. A more extensive discussion of the ASME peer review methodology used for the Fuel Cell Program Peer Review Meeting is provided in Appendix A. A copy of the meeting agenda is provided in Appendix B, and an introduction to the Peer Review Panel members is provided in Appendix C.

Peer Review Criteria and Peer Review Criteria Forms

ASME developed a set of agreed-upon review criteria to be applied to the projects under review at this meeting. The review criteria were provided to the Review Panel and PIs in advance of the Peer Review Meeting, and assessment sheets with the review criteria were pre-loaded (one for each respective project) onto laptop computers for each Panel member. During the meeting, the panel members assessed the Strengths and Weaknesses for each project before providing both Recommendations and Action Items, and completed the review criteria forms in closed sessions. A more detailed explanation of this process and a sample Peer Review Criteria Form are provided in Appendix D.

The following sections of this report summarize findings from the Fuel Cell Program Peer Review Meeting and are organized as follows:

II. Summary of Projects Reviewed in 2008 Fuel Cell Program Peer Review
A list of the 18 projects reviewed and the selection criteria.

III. An Overview of the Evaluation Scores in 2008
Average scores and a summary of evaluations, including analysis and recommendations.

IV. Summary of Key Project Findings
An overview of key findings from project evaluations.

V. Process Considerations for Future Peer Reviews
Lessons learned in this review that may be applied to future peer reviews.

II. SUMMARY OF PROJECTS REVIEWED IN 2008 FUEL CELL PROGRAM PEER REVIEW

NETL selected the projects that were reviewed by the independent ASME Review Panel for the Fuel Cell Program Peer Review. Selected projects met the following criteria:

- Key projects within the Fuel Cell Program or related projects being conducted in NETL's Office of Research and Development (ORD) and Office of Systems Analysis and Planning (OSAP)
- Projects that have been active for at least 12 months (i.e., would have conducted sufficient work to be evaluated)
- Projects that have at least 12 months of performance remaining (i.e., sufficient time remaining to benefit from Peer Review comments/recommendations)
- Projects that, collectively, represent 80% of the program portfolio (on a dollar basis), consistent with NETL's Strategic Center for Coal *Process for Conducting Independent Project Peer Reviews* (January 2008)

PROJECTS REVIEWED

01: DE-FC26-04NT41837

Coal-Based Solid-Oxide Fuel Cell Power Plant Development
FuelCell Energy, Inc.

02: DE-FC26-02NT41246

Solid State Energy Conversion Alliance
Delphi Automotive Systems

03: DE-FC26-06NT42812

Santa Clara County California Solid-Oxide Fuel Cell Project
Santa Clara County California

04: DE-FC26-05NT42613

Coal-Gas-Fueled SOFC Hybrid Power Systems with CO_2 Separation
Siemens Power Generation – Pittsburgh

05: DE-FC26-06NT42810

Solid-Oxide Fuel Cell Technology Stationary Power Application Project (NC)
Siemens Power Generation – Pittsburgh

06: DE-FC26-05NT42614

Solid-Oxide Fuel Cell Coal-Based Power Systems
GE Global Research

07: DE-FC26-05NT42513

Evaluation of a Functional Interconnect System for Solid-Oxide Fuel Cells
Allegheny Technologies, Inc.

08: FEAA066

Reliability of Materials and Components for Solid-Oxide Fuel Cells
Oak Ridge National Laboratory

09: FWP-40552

Low-Cost Modular SOFC Development—Refractory Glass
Pacific Northwest National Laboratory

10: ORD-08-220621C

Coal-Based Fuel Cells—University Research Initiative Projects
NETL Office of Research & Development

11: FWP-49071

Solid-Oxide Fuel Cell Research and Development—Synchrotron
Argonne National Laboratory

12: MSD-NETL-01

Development of Inexpensive Metal Alloy Electrodes for Cost-Competitive Solid-Oxide Fuel Cells
Lawrence Berkeley National Laboratory

13: DE-FC26-02NT41572

Functionally Graded Cathodes for Solid-Oxide Fuel Cells
Georgia Tech Research Corporation

14: DE-FC26-05NT42516

Development of Sulfur- and Carbon-Tolerant Reforming Alloy Catalysts Aided by Fundamental Atomistic Insight
University of Michigan

15: FWP-40552

Low-Cost Modular SOFC Development—Modeling
Pacific Northwest National Laboratory

16: ORD-07-220611

Fuel Processing & Hydrogen Production
NETL Office of Research and Development

17: ORD-08-220621A

Coal-Based Fuel Cells—Contaminant Testing
NETL Office of Research and Development

18: DE-FC26-02NT41567

A Low-Cost Soft-Switched DC/DC Converter for Solid-Oxide Fuel Cells
Virginia Polytechnic Institute & State University

A short summary of each of the above projects is presented in Appendix E.

III. AN OVERVIEW OF THE EVALUATION SCORES IN 2008

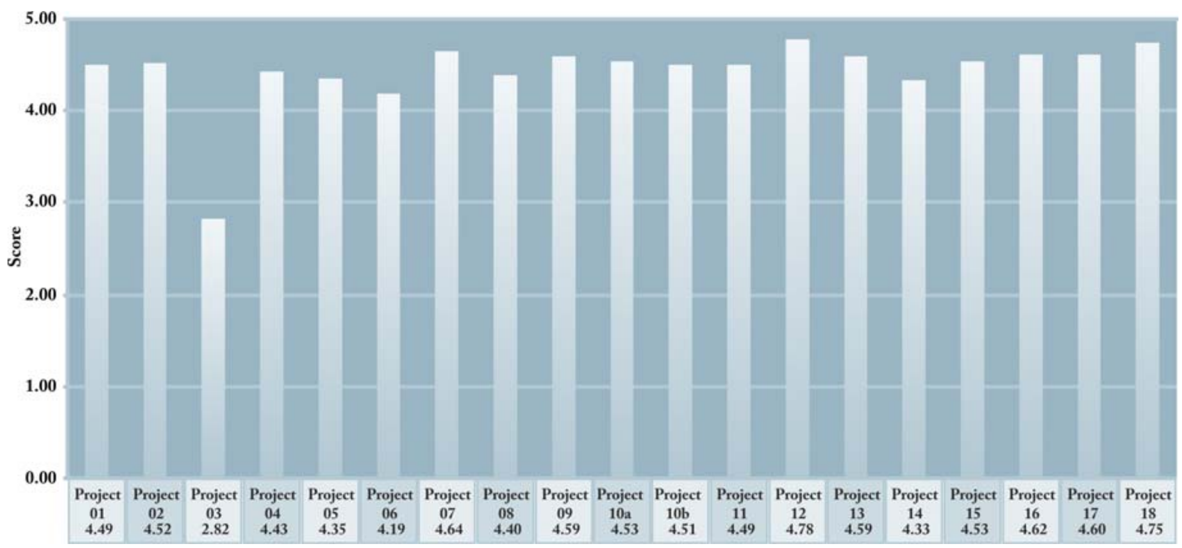
The ASME team, in cooperation with NETL and with input from the Peer Review Panel, continues to enhance and refine the peer review process. A copy of the Peer Review Criteria Form and a detailed explanation of the process and the criteria definitions are provided in Appendix D.

For each of the nine review criteria, an individual reviewer was asked to score the project as one of the following:

- Effective (5)
- Moderately Effective (4)
- Adequate (3)
- Ineffective (2)
- Results Not Demonstrated (1)

Figure 1 shows the average score of all nine review criteria for each of the 18 projects reviewed in the Fuel Cell Program. With the exception of the lowest ranked project (an outlier at 2.82), the range of scores across all projects is narrow, from the second lowest overall average score of 4.19—well above "Moderately Effective"—to the highest overall averaged score of 4.78—very close to a perfect "Effective" score of 5.0. The average (excluding the outlier) of these individual "overall average" project scores is 4.52—indicating the collective project set ranked well above "Moderately Effective." Inclusion of the lowest ranked project, at 2.82, lowers this overall average to 4.43.

FIGURE 1 OVERALL SCORING AVERAGE – BY PROJECT



It can also be beneficial to look at the average scores for all projects across the nine review criteria. The combined average scores for all review criteria are shown in Table 1. Again, it is impressive that the median overall average score for the nine review criteria, across the 18 fuel cell projects reviewed, was 4.5, and that for all criteria the average score was 3.9 or higher (i.e., nearly "Moderately Effective" or better). The highest-ranking review criteria was "Existence of Clear, Measurable Milestones," with an average score across all projects of 4.7. This reflects a continuing effort by DOE to ensure responsible and effective R&D.

TABLE 1 SCORES BY REVIEW CRITERION

Criterion	Average	Highest	Lowest*
Existence of Clear, Measurable Milestones	4.7	5.0	4.6 / 3.0
Rate of Progress	4.6	4.9	4.3 / 3.4
Technical Approach	4.6	5.0	4.4 / 2.9
Economic Analysis	3.9	4.6	3.4 / 1.8
Utilization of Government Resources	4.6	5.0	3.8 / 2.6
Scientific and Technical Merit	4.5	4.9	4.1 / 2.5
Anticipated Benefits if Successful	4.5	5.0	4.2 / 3.4
Commercialization Potential	4.2	5.0	3.7 / 3.0
Possible Adverse Effects Considered	4.2	4.8	4.0 / 2.9

*To present a more accurate view of the lowest scores, two values have been given. The first value is the lowest average score of all projects except project 03: DE-FC26-06NT42812, Santa Clara County California Solid-Oxide Fuel Cell Project. The second value is the lowest average score of all projects. This distinction is made because project 03 received significantly lower scores than the other projects reviewed.

A sample copy of the Peer Review Criteria Form is provided in Appendix D.

IV. SUMMARY OF KEY FINDINGS

This section offers a summary of key findings from across all of the 18 individual projects evaluated.

General Project Strengths

In general, Reviewers found the projects to be sound and strong. All but one project scored an average of 4.2 or better across all review criteria, with most projects scoring significantly higher. These scores indicate that the Reviewers felt very strongly about the quality and significance of the research being conducted by the Fuel Cell Program. They found both the breadth and strength of the projects to be impressive, effectively addressing issues from basic and applied R&D to proof of concept and demonstration, and found the teams responsible for these projects to be both competent and knowledgeable in their areas of expertise.

Several Reviewers stated they found the Fuel Cell Program to be among the strongest research programs they have seen. Projects also scored well by individual criteria. The following projects earned a perfect 5.0 for the stated criteria:

- Project 2: Solid State Energy Conversion Alliance, performed by Delphi Corporation—Commercialization Potential
- Project 9: Low-Cost Modular SOFC Development—Refractory Glass, performed by Pacific Northwest National Laboratory (PNNL)—Existence of Clear, Measurable Milestones
- Project 10a/b: Coal-Based Fuel Cells—University Research Initiative Projects, performed by National Energy Technology Laboratory and Carnegie Mellon University—Utilization of Government Resources
- Project 12: Development of Inexpensive Metal Alloy Electrodes for Cost-Competitive Solid-Oxide Fuel Cells, performed by Lawrence Berkeley National Laboratory—Technical Approach; Anticipated Benefits if Successful
- Project 15: Low-Cost Modular SOFC Development—Modeling, performed by Pacific Northwest National Laboratory—Utilization of Government Resources
- Project 16: Fuel Processing & Hydrogen Production, performed by National Energy Technology Laboratory—Utilization of Government Resources
- Project 17: Coal-Based Fuel Cells – Contaminant Testing (Multi-Cell Array and Contaminant Testing), performed by National Energy Technology Laboratory—Utilization of Government Resources

Four projects (10 a/b, 15, 16, and 17) earned a 5.0 for “Utilization of Government Resources,” clearly demonstrating the commitment of the DOE to effective R&D. Reviewers found these projects, along with several others, to have effectively leveraged available resources, using state-of-the-art tools and techniques above and beyond the level of funding to analyze and develop fuel cells and fuel cell components.

The highest-rated project was Project 12, Development of Inexpensive Metal Alloy Electrodes for Cost-Competitive Solid-Oxide Fuel Cells, performed by Lawrence Berkeley National Laboratory. This project averaged 4.8 out of 5.0 across all criteria, and earned 5.0 in both “Technical Approach” and “Anticipated Benefits if Successful.” Reviewers found that this project, as well as five others, did not require specific Action Items.

Many projects were complimented for demonstrating exceptional communication abilities, effectively reaching out to the fuel cell community and to commercial and industrial companies with relevant experience. Reviewers specifically complimented several project teams for demonstrating a commercial awareness not common to researchers focusing on fundamental R&D. Nearly all teams were seen as technically superior, with the Panel recognizing several of the teams as being world renowned in their particular field and having successfully challenged some of the basic assumptions which had, until now, prevailed.

Reviewers supported the general trend toward increasing cell size to increase power output, in addition to efforts to run large numbers of cells in series. The ability of several project teams to achieve vastly increased fuel cell size with low to negligible increases in cell degradation impressed the Reviewers.

Reviewers also felt that there was a great amount of synergy between projects, as many not only built from and relied on the results of other projects, but returned results that strengthened other projects in turn. Reviewers commented that many projects opened the possibility for further productive research using slightly altered assumptions, materials, or test conditions.

The Reviewers found many of the projects focusing on modeling efforts to be superior in both technical ability and realistic applicability. These projects were seen as the foundations for future exploratory projects, vastly decreasing the need for a “trial-and-error” approach or an approach based on anecdotal evidence. The new modeling techniques will more easily allow those new and inexperienced in the field to achieve proficiency far more quickly than would otherwise be possible.

General Project Weaknesses

Several of the projects used unrealistic or generous assumptions (e.g., low levels of sulfur and other contaminants in the input gas, ambitious predictions of cost reduction in manufacturing, etc.), Reviewers noted, while many were cited for performing only short-term testing (though members of the Review Panel were quick to note that long-term testing may not be within project scope or economically feasible for many of these projects). In general, Reviewers found that the successful development of many of the projects would lead to additional steps in the fuel cell production process, potentially increasing complexity and the cost of initial models (though the resulting increases in efficiency and durability would likely be beneficial as fuel cell producers achieve economies of scale).

Several projects were found to suffer from an unjustified selection of focus. The Reviewers felt that PIs should have made more exhaustive efforts into modeling and theoretical calculations to guide their projects. As a consequence of this, however, the Reviewers felt that there was a vast amount of research yet to be explored through small changes in project assumptions and/or materials.

The criterion with the lowest average score—3.9—across all projects was “Economic Analysis,” though that score still neared a “Moderately Effective” rating. Though this was a commendable rating considering many of the projects are primarily fundamental R&D projects, the Panel felt that many of the projects would benefit from an early understanding of how their research will affect the development of commercial fuel cells.

Issues for Future Consideration

On the whole, the Reviewers were extremely impressed by the technical expertise, knowledge, and productivity of the researchers. However, Reviewers felt that many projects would have benefited from early modeling to complement the experimental investigation being pursued. The Panel noted that a large area for exploration exists in performing projects that are similar to those being conducted, but that use slightly modified materials and/or assumptions. The Panel also expressed that many of the projects could benefit from the use of less idealized operating conditions to achieve more realistic predictions of performance, especially in terms of potential contaminants in the gas stream.

The Reviewers viewed the early consideration of economic potential and early economic analysis, two of the weakest performing criteria, as areas where general improvement can be made. Acknowledging the inherent difficulty in predicting economic viability in early, basic R&D projects, the Reviewers felt that several of the projects researchers did not sufficiently convey an understanding of how the final result of their research would be implemented. Additionally, the Reviewers were not comfortable with the fact that several projects were relying upon an assumed manufacturing cost reduction curve to meet cost goals.

Reviewers commented that while impressive yields have been reached, there is still a long way to go, as commercial products must have an extremely small possibility for malfunction. Project leads need to recognize and ensure the fulfillment of this goal.

Finally, the Reviewers were in general agreement that many of the projects need only maintain the same level of superior ability, focus, and research that was seen throughout the peer review process to ensure eventual success.

V. PROCESS CONSIDERATIONS FOR FUTURE PEER REVIEWS

Review Panel members involved in the peer review offered constructive comments on the review process and possible modifications for the future. Comments were provided at the conclusion of the Peer Review Meeting. The following is a brief summary of ideas recommended for use in planning future project review sessions.

General Process Comments

All involved unanimously agreed that the current Peer Review process is excellent and requires little or no modification. There was high praise both for the facilitation of the meeting and the superb work of the support staff. Panel members found the computerized score tabulation method effective and beneficial, as it allowed for quick display of a project's average score.

The Review Panel liked the venue selected for the review (the Sheraton Station Square in Pittsburgh PA) as it was located downtown rather than a more isolated area, such as the airport.

Fuel Cell Program and Projects Reviewed

The presentation and Q&A were held in closed sessions consisting only of DOE, TMS, and ASME personnel, the Review Panel, and the project team, allowing for candid discussion of the material. However, several Panel members felt that the PIs could have presented more details on certain aspects of these projects without disclosing proprietary information.

Meeting Agenda

The Panel agreed that the information in the DOE roadmap presentation at the beginning of the review should be reinforced briefly at the beginning of each PI presentation. Many Reviewers at times felt that they lacked context for a project, which prevented them from seeing how the project related to the Fuel Cell Program as a whole. As a result of this, the Panel found it necessary to direct programmatic questions to NETL staff during the first two days. Briefly presenting how each project fits within the overall Fuel Cell Program, before each PI presentation, would address this issue and should be considered for future reviews.

The meeting agenda was adjusted to allow for five additional minutes of Q&A at the expense of discussion time, allowing the Panel to garner additional information from the presenter, if necessary. The Panel agreed this adjustment was helpful and would recommend a similar adjustment in future reviews.

Presentations and Evaluations

According to the Review Panel, many presentations lacked some information pertinent to the review making it difficult to address certain review criteria. Panel members took advantage of the extended Q&A session to request the additional information from the PIs.

Reviewers agreed that some of the criteria were ill-defined or had definitions that did not apply equally to both Industry Team and Core Technology projects, particularly "Commercialization Considerations" and "Economic Analysis." The Panel decided to consider project maturity in determining scores for these criteria, rather than holding all projects to the same standard. Several Reviewers also struggled with the criteria definition for "Adverse Effects if Successful" and recommended the definition be reconsidered for future reviews.

Review Panel

Many in the Panel thanked DOE for the opportunity to participate in this review, citing it as an enjoyable and educational experience.

APPENDICES

APPENDIX A: ASME PEER REVIEW METHODOLOGY

The American Society of Mechanical Engineers (ASME) has been involved in conducting research since 1909 when it started work on steam boiler safety valves. Since then, the Society has expanded its research activities to a broad range of topics of interest to mechanical engineers. ASME draws on the impressive breadth and depth of technical knowledge among its members and, when necessary, experts from other disciplines for participation in ASME-related research programs. In 1985, ASME created the Center for Research and Technology Development (CRTD) to coordinate ASME's research programs.

As a result of the technical expertise of ASME's membership and its long commitment to supporting research programs, the Society has often been asked to provide independent, unbiased, and timely reviews of technical research by other organizations, including the federal government. After several years of experience in this area, the Society has developed a standardized approach to reviewing research projects. The purpose of this section is to give a brief overview of the review procedure established for the U.S. Department of Energy (DOE)/National Energy Technology Laboratory (NETL) 2008 Fuel Cell Program Peer Review.

ASME Knowledge and Community (K&C) Sector

One of the five sectors responsible for the activities of ASME's 127,000 members worldwide, the K&C Sector is charged with disseminating technical information, providing forums for discussions to advance the mechanical engineering profession, and managing the Society's research activities.

Center for Research and Technology Development (CRTD)

The mission of the CRTD is to effectively plan and manage the collaborative research activities of ASME to meet the needs of the mechanical engineering profession as defined by the ASME members. The center is governed by the Board on Research and Technology Development (BRTD). The BRTD has organized more than a dozen research committees in specific technical areas. Day-to-day operations of the CRTD are handled by the director of research and his staff. The director of research serves as staff to the Peer Review Executive Committee, handles all logistical support for the review panel, provides facilitation of the actual review meeting, and prepares all summary documentation.

Board on Research and Technology Development (BRTD)

The BRTD governs the activities of the CRTD. ASME members with suitable industrial, academic, or governmental experience in the assessment of priorities for research and development, as well as in the identification of new or unfulfilled needs, are invited to serve on the BRTD and to function as liaisons between BRTD and the appropriate ASME sectors, boards, and divisions.

Fuel Cell Program Peer Review Executive Committee

For each set of projects to be reviewed, the BRTD convenes a Peer Review Executive Committee to oversee the review process. The Executive Committee is responsible for: seeing that all ASME rules and procedures are followed; reviewing and approving the qualifications of those asked to sit on the review panel; ensuring that there are no conflicts of interest in the review process; and reviewing all documentation coming out of the project review. There must be at least three members of the Peer Review Executive Committee, and those members must have experience relevant to the program being reviewed. Members of the 2008 Fuel Cell Program Peer Review Executive Committee were as follows:

- **Richard T. Laudenat, Chair.** Mr. Laudenat is the Senior Vice-President of the ASME Knowledge and Communities Sector. He was previously a Vice-President of the ASME Energy Conversion Group and was a member of the ASME Energy Committee.
- **William Stenzel**, of Sargent and Lundy. Mr. Stenzel is a former chair of the ASME Power Division and past member of the ASME Energy Committee.
- **William Worek**, of the University of Illinois. Dr. Worek is a past Vice-President of the ASME Energy Resources Group and former chair of the ASME Solar Energy Division. He currently serves on the ASME Mechanical Engineering Department Heads Committee.

Fuel Cell Program Peer Review Panel

The Fuel Cell Program Peer Review Executive Committee accepted résumés for proposed Fuel Cell Program Peer Review Panel members from CRTD, from a limited call to ASME members with relevant experience in this area, and from the DOE/NETL program staff. From these sources, the ASME Peer Review Executive Committee selected a nine-member Panel and agreed that they had the experience necessary to review the broad range of projects under this program, and did not present any conflicts of interest. The Review Panel members needed experience in several subject matters, including: SOFC planar, stack, and cell design; SOFC modeling and optimization; power system design; power plant application; turbine design; coal syngas; integrated coal gasification fuel cell (IGFC) systems; R&D priorities, policy, and deliverables; cost and economic feasibility; carbon dioxide separation; carbon capture; gas separation; ceramic metallic alloys; high temperature coatings, oxides, and durability; and basic fluid dynamics and thermodynamics.

Meeting Preparation and Logistics

Prior to the meeting, the project team for each project being reviewed was asked to submit an 11-page Project Summary Sheet including project goals, purpose, accomplishments to date, etc. A standard set of specifications for preparing this document was provided by CRTD. These Project Summary Sheets were collected and sent to the Peer Review Panel for background reading prior to the meeting.

Also in advance of the review meeting, CRTD gave project teams a standard presentation format and complete set of instructions for the oral presentations to the review panel. All presentations were created in PowerPoint format, and Reviewers were also given hard-copy handouts of these slides.

Project Presentations, Evaluations, and Discussion

At the Fuel Cell Program Peer Review Meeting, presenters were held to a time limit of 45 minutes, or longer for large or multi-lab projects, to allow sufficient time for all presentations within the five-day meeting period. After each presentation, the project team participated in a question-and-answer session with the Review Panel for 25 minutes.

Following each presentation and Q&A, the Review Panel spent 25 minutes evaluating the projects based on the presentation material. To start, each reviewer scored the project against a set of predetermined peer review criteria. A copy of the Peer Review Criteria Form and a detailed explanation of the process and the criteria definitions are provided in Appendix D. The following nine criteria were used:

- Existence of Clear, Measurable Milestones
- Rate of Progress
- Technical Approach
- Economic Analysis
- Utilization of Government Resources
- Scientific and Technical Merit
- Anticipated Benefits if Successful
- Commercialization Potential

- Possible Adverse Effects Considered

For each of these Review Criteria, individual Reviewers scored each project as one of the following:

- Effective (5)
- Moderately Effective (4)
- Adequate (3)
- Ineffective (2)
- Results Not Demonstrated (1)

To facilitate the evaluation process, TMS provided Reviewers with laptop computers that were pre-loaded with Peer Review Criteria Forms for each project. After scoring the projects on these criteria, the Panel members provided written comments about each project. The Review Panel then discussed the project for the purpose of defining: project Strengths, project Weaknesses, Recommendations for other possible activities, and a list of Action Items that the team must address.

APPENDIX B: MEETING AGENDA

U.S. Department of Energy - Office of Fossil Energy - National Energy Technology Laboratory

2008 Fuel Cells Peer Review
Sheraton Station Square
April 21 - 25, 2008

AGENDA

MONDAY, APRIL 21, 2008 - HASELTON I & II

8:00 - 9:00 a.m.	Continental Breakfast/Registration - HASELTON I & II FOYER
9:00 - 9:45 a.m.	Peer Review Panel Kick Off Meeting - Open to NETL and ASME staff only - Review of ASME Process - Michael Tinkleman/Ross Brindle, ASME - Meeting logistics/completion of forms - Steven Ostheim/Charles Schmidt, TMS - Role of NETL - José Figueroa, NETL
9:45 - 10:45 a.m.	Overview - Open to NETL and ASME staff only - Program Manager - Wayne Surdoval
10:45 - 11:00 a.m.	**BREAK** - HASELTON I & II FOYER
11:00 - 12:00 p.m.	***Project # 41837*** - Coal-Based Solid Oxide Fuel Cell Power Plant Development - *Jody Doyon*, **Fuel Cell Energy, Inc.**
12:00 - 12:20 p.m.	Q&A
12:20 - 12:55 p.m.	Discussion, evaluation, and written comments
12:55 - 2:00 p.m.	**Lunch (on your own)**
2:00 - 3:00 p.m.	***Project # 41246*** - Solid State Energy Conversion Alliance - *Steven R. Shaffer*, **Delphi Corporation**
3:00 - 3:20 p.m.	Q&A
3:20 - 3:55 p.m.	Discussion, evaluation, and written comments
3:55 - 4:10 p.m.	**BREAK** - HASELTON I & II FOYER
4:10 - 4:55 p.m.	***Project # 42812*** - Santa Clara County California Solid Oxide Fuel Cell Project - *Caroline Judy*, **Santa Clara County California**
4:55 - 5:15 p.m.	Q&A
5:15 - 5:45 p.m.	Discussion, evaluation, and written comments

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Tuesday, April 22, 2008 - Haselton I & II

7:00 - 8:00 a.m.	Continental Breakfast/Registration - Haselton I & II Foyer
8:00 - 9:00 a.m.	***Project # 42613*** - Coal Gas Fueled SOFC Hybrid Power Systems with CO_2 Seperation - *Joseph F. Pierre*, **Siemens Power Generation**
9:00 - 9:20 a.m.	Q&A
9:20 - 9:55 a.m.	Discussion, evaluation, and written comments
9:55 - 10:10 a.m.	**BREAK** - Haselton I & II Foyer
10:10 - 10:55 a.m.	***Project # 42810*** - Solid Oxide Fuel Cell Technology Stationary Power Application Project (NC) - *Joseph F. Pierre*, **Siemens Power Generation**
10:55 - 11:15 a.m.	Q&A
11:15 - 11:45 a.m.	Discussion, evaluation, and written comments
11:45 - 12:45 p.m.	**Lunch (on your own)**
12:45 - 1:30 p.m.	***Project # 42614*** - Solid Oxide Fuel Cell Coal-Based Power Systems - *Matthew Alinger*, **GE Global Research**
1:30 - 1:50 p.m.	Q&A
1:50 - 2:20 p.m.	Discussion, evaluation, and written comments
2:20 - 2:35 p.m.	**BREAK** - Haselton I & II Foyer
2:35 - 3:20 p.m.	***Project # 42513*** - Evaluation of a Functional Interconnect System for Solid Oxide Fuel Cells - *James Rakowski*, **Allegheny Technologies**
3:20 - 3:40 p.m.	Q&A
3:40 - 4:10 p.m.	Discussion, evaluation, and written comments

Wednesday, April 23, 2008 - Haselton I & II

7:00 - 8:00 a.m.	Continental Breakfast/Registration - Haselton I & II Foyer
8:00 - 8:45 a.m.	***Project # FEAA066*** - Reliability of Materials and Components for Solid Oxide Fuel Cells - *Edgar Lara-Curzio*, **Oak Ridge National Laboratory**
8:45 - 9:05 a.m.	Q&A
9:05 - 9:35 a.m.	Discussion, evaluation, and written
9:40 - 10:25 a.m.	***Project # FWP-40552*** - Low Cost Modular SOFC Development - **REFRACTORY GLASS** - *Jeff Stevenson*, **Pacific Northwest National Laboratory**
10:25 - 10:45 a.m.	Q&A
10:45 - 11:15 a.m.	Discussion, evaluation, and written comments
11:15 - 11:25 a.m.	**BREAK** - Haselton I & II Foyer

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Thursday, April 24, 2008 - Haselton I & II

1:05 - 2:05 p.m.	**Lunch (on your own)**
2:05 - 2:50 p.m.	***Project # ORD-07-220611*** - Fuel Processing & Hydrogen Production - *David A. Berry*, **National Energy Technology Laboratory**
2:50 - 3:10 p.m.	Q&A
3:10 - 3:40 p.m.	Discussion, evaluation, and written comments
3:40 - 3:55 p.m.	**BREAK** - **Haselton I & II Foyer**
3:55 - 4:40 p.m.	***Project # ORD-08-220621a*** - Coal Based Fuel Cells - Contaminant Testing (Multi-Cell Array and Contaminant Testing) - *Randy Gemmen*, **National Energy Technology Laboratory**
4:40 - 5:00 p.m.	Q&A
5:00 - 5:30 p.m.	Discussion, evaluation, and written comments

Friday, April 25, 2008 - Haselton I & II

7:00 - 8:00 a.m.	Continental Breakfast/Registration - **Haselton I & II Foyer**
8:00 - 8:45 a.m.	***Project # 41567*** - A Low-Cost Soft-Switched DC/DC Converter for Solid Oxide Fuel Cells - *Jason Lai*, **Virginia Polytechnic Institute & St. Univ.**
8:45 - 9:05 a.m.	Q&A
9:05 - 9:35 a.m.	Discussion, evaluation, and written comments
9:35 - 9:45 a.m.	**BREAK** - **Haselton I & II Foyer**
9:45 - 12:15 p.m.	Overall meeting Wrap-up 15 minutes/reviewers x 10

APPENDIX C: PEER REVIEW PANEL MEMBERS

After reviewing the scientific areas and issues addressed by the 18 projects to be reviewed, the CRTD staff and the ASME Peer Review Executive Committee, in cooperation with the NETL project manager, identified the following areas of expertise that the 2008 Fuel Cell Program Peer Review Panel would need to possess:

- SOFC planar, stack, and cell design
- SOFC modeling/optimization
- Power system design/power plant application/turbine design
- Coal synthesis gas (syngas)/integrated coal gasification fuel cells
- R&D priorities policy and deliverables
- Costing and economic feasibility
- Carbon dioxide separation/carbon capture/gas separation
- Ceramic metallic alloys
- High temperature coatings/oxides/durability
- Basic fluid dynamics and thermodynamics

It was also important that the Peer Review Panel represent the distinctly different perspectives of academia, industry, government, and non-profit sectors.

Considering the areas of expertise listed above, the CRTD carefully reviewed the résumés of all those who had previously served on prior ASME Review Panels for DOE, acknowledging the benefit of their previous experience in this form of Peer Review Meeting, and a number of new submissions both from DOE and those resulting from a limited call to ASME members with relevant experience. It was determined that two of those who had served on prior ASME Review Panels were well qualified to serve on the Fuel Cell Program Review Panel.

Appropriate résumés were then submitted to the Fuel Cell Program Peer Review Executive Committee for review. Nine members were selected for the 2008 Fuel Cell Program Peer Review Panel:

- Dr. Thomas L. Cable, University of Toledo/NASA Glenn Research Center
- Dr. Minking K. Chyu, University of Pittsburgh, Review Panel Chair
- Dr. Brian Gleeson, University of Pittsburgh
- Dr. J. Stephen Herring, Idaho National Laboratory
- Dr. William R. Owens, Princeton Energy Resources International
- Dr. Arthur J. Soinski, California Energy Commission
- Mr. James C. Sorensen, consultant
- Dr. David C. Thomas, consultant
- Dr. Michael R. von Spakovsky, Virginia Polytechnic Institute and State University

A brief summary of their qualifications follows. Panel members reviewed pre-presentation materials and spent five days evaluating projects and providing comments. Panelists received an honorarium for their time as well as reimbursement of travel expenses.

2008 Fuel Cell Program Peer Review Panel Members

Thomas L. Cable, Ph.D.

Dr. Cable is a specialist in solid oxide fuel cells and regenerative fuel cells. He is presently employed as the chief scientist in the Ceramics Branch of the University of Toledo/NASA Glenn Research Center. In this position, he serves as the technical lead in the development of a new, all-ceramic SOFC design for aeronautic applications. Prior to this, he was employed as chief scientist at McDermott Technology Inc. (MTI) and was principle investigator in cell development of the SOFC fuel cell stack design. Dr. Cable holds several patents in SOFC design and direct conversion of hydrocarbon with SOFCs. Dr. Cable received a B.S. in Chemistry/Chemical Engineering and Ph.D. in chemical and fuels engineering from the University of Utah. He also completed a post doctoral fellowship at Brigham Young University.

Minking K. Chyu, Ph.D., Review Panel Chair

Dr. Chyu is chair of the Department of Mechanical Engineering and Materials Science and the Leighton Orr (endowed) Professor of Engineering at the University of Pittsburgh. Dr. Chyu's primary research area lies in thermo-fluid issues related to power and propulsion system, material processing, and microsystem technology. Major projects he has conducted include convective cooling of gas turbine airfoils, thermal control of rotating machinery, thermal measurement and imaging techniques, and transport phenomena in adaptive flow control and fabrication of micro-structures. He is a Fellow of ASME and is currently a member of the Heat Transfer Technical Committee in Gas Turbines (K-14) and is associate editor of the *ASME Journal on Heat Transfer*. Dr. Chyu received a B.S. in nuclear engineering at the National Tsing Hua University in Taiwan, a M.S. in applied mechanics at the University of Cincinnati, and a Ph.D. in mechanical engineering from the University of Minnesota.

Dr. Chyu was chosen to lead the review panel. His responsibilities included acting as a technical lead for the Review Panel, working with ASME to clarify any process questions Panel members raised, and suggesting adjustments to the Peer Review process that improve the Review Panel's ability to fairly and accurately review the projects being reviewed.

Brian Gleeson, Ph.D.

Dr. Gleeson is the Henry S. Tack Professor in the Department of Mechanical Engineering and Materials Science at the University of Pittsburgh. His primary research focus is on the thermodynamics and kinetics of gas/solid and solid/solid reactions. His work places particular emphasis on the high-temperature degradation of metallic alloys and coatings. Related to this, his current research interests include active and passive high-temperature oxidation of alloys and coatings; deposition and characterization of metallic coatings; diffusion and thermodynamic treatments of both gas/solid and solid/solid interactions; and structure/property relationships of materials. He is the editor of the international journal *Oxidation of Metals.* Dr. Gleeson has a B.S. and M.S. in materials science and engineering from the University of Western Ontario in Canada, and a Ph.D. in materials science and engineering from the University of California at Los Angeles. He also completed a post doctoral fellowship at the University of New South Wales in Australia.

J. Stephen Herring, Ph.D.

Dr. Herring is technical director of High Temperature Electrolysis in the DOE Nuclear Hydrogen Initiative at the Idaho National Laboratory (INL.) He originated concepts and formed a team for the development of solid oxide electrolytic cells. His research has grown to include the use of nuclear heat and electricity for the production of synthetic diesel, jet fuel, and gasoline and the recovery and upgrading of unconventional fossil fuels such as oil sands, oil shale, and heavy crude. His previous responsibilities at INL include the evaluation of nuclear designs in conjunction with electrolytic and thermochemical processes for the production of elemental hydrogen and other hydrogen-transport compounds. Dr. Herring received B.S. degrees with distinction in both mechanical and electrical engineering from the Iowa State University and a Ph.D. in nuclear engineering at the Massachusetts Institute of Technology.

William R. Owens, Ph.D.

Dr. Owens is vice president of fossil energy projects at Princeton Energy Resources International. He has extensive experience in system engineering principles, cost estimation, project economics, environmental control technologies, project management, and project control of power generation systems including conventional and emerging technologies. This experience includes fuel cells, turbines, gasifiers, fluidized bed combustors, etc. Dr. Owens's experience includes systems with bituminous coal, anthracite coal, and sub-bituminous western coals. He has worked with alternate fuel systems including natural gas, hydrogen, gasifier fuel-gas, oil, and oil-shale systems. Dr. Owens has provided DOE with detailed support in outreach programs, deregulation of the electric utility industry, and international programs. He has a B.S. from Pennsylvania State University, a M.S. from Drexel University, and a Ph.D. from the University of Maryland. All of his degrees are in mechanical engineering.

Arthur J. Soinski, Ph.D.

Dr. Soinski is the team lead of the Environmentally Preferred Advanced Generation (EPAG) Public Interest Energy Research Program (PIER) at the California Energy Commission. He is the technical manager of a team of scientists and engineers that fund electricity generation research, development, and demonstration (RD&D) projects in an $83 million per year public benefits program and he is responsible for setting program direction, RD&D priorities and goals based on state energy and environmental policy, legislative direction, issues assessments, and market needs. The portfolio of EPAG-funded projects includes advanced reciprocating engines, microturbines, industrial turbines, fuel cells, Stirling engines, combined heating, cooling and power systems, and thermochemical fuel reforming. He has a B.S. in chemistry from the University of Dayton and an M.S. and Ph.D. in chemistry from the University of California, Berkeley.

James C. Sorensen

Mr. Sorensen is a consultant specializing in the conception and development of clean coal and other energy programs with a focus on integrated gasification combined cycle (IGCC), oxy-fuel combustion, gas-to-liquids (GTL), and air separation and hydrogen/syngas technologies. Prior to this, he worked for Air Products and Chemicals both as director of new markets and as director of gasification and energy conversion. While in these positions, his achievements included developing and selling a $26 million Ultra Clean Fuels technology development program that was selected by DOE, selling a $30 million single train separation facility for a 250 mw IGCC power plant, proposing and developing a $22.5 million fossil fuel R&D program selected by DOE, and leading Air Products efforts on a multi-team proposal selected by DOE for a $180 million Clean Coal Technology award. Mr. Sorensen is the founding chairman of the Gasification Technologies Council. He received a B.S. in chemical engineering from the California Institute of Technology and earned a M.S. in chemical engineering from Washington State University. Mr. Sorensen also earned a MBA in general management from Harvard Business School.

David C. Thomas, Ph.D

Dr. Thomas has served on the NETL Carbon Sequestration Program Review Board since its inception and edited the Results Volumes from the Carbon Capture Project, a multi-company, multi-national research consortium on CO_2 sequestration. Prior to retiring from BP, where he was manager of CO_2 mitigation technology, he held a broad range of positions in BP & Amoco Corporation's technology development, research, management, and strategy development organizations. He worked throughout his career in support of oil exploration and production, refining, and chemicals manufacture as both a technical specialist and research manager. He has followed energy technology development, including fuel cells, solar-electric, and wind power, as both a personal and professional interest. Dr. Thomas is a founding life member and past president of the Society of Core Analysis. He is a life member of the Society of Petroleum Engineers and a 40-year member of the American Chemical Society. Dr. Thomas holds a Ph.D. in physical chemistry from the University of Oklahoma, a MS in inorganic chemistry from the University of Akron and a BS in chemistry from Baker University. His area of specialization within physical chemistry was surface and interfacial reactions. He has published over 45 papers and five patents.

Michael R. von Spakovsky, Ph.D

Dr. von Spakovsky is a professor of mechanical engineering and director of the Center for Energy Systems Research at the Virginia Polytechnic Institute and State University. He teaches undergraduate and graduate level courses in thermodynamics, kinetic theory, fuel cell systems, and energy system design. His research interests include computational methods for modeling and optimizing complex energy systems; methodological approaches for integrated synthesis, design, operation, control, and diagnosis of such systems; and fuel cell applications for both transportation and distributed power generation. He is associate editor for the *ASME International Journal of Fuel Cell Science and Technology* and an ASME Fellow. He is also editor-in-chief of the *International Journal of Thermodynamics* as well as chairman of the Executive Committee of the International Center for Applied Thermodynamics. He received a B.S. in aerospace engineering from Auburn University and a M.S. and Ph.D. in mechanical engineering from the Georgia Institute of Technology.

APPENDIX D: PEER REVIEW CRITERIA FORM

PEER REVIEW PANEL MEMBERS
U. S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
2008 FUEL CELL PROGRAM
PEER REVIEW MEETING
APRIL 21 TO 25, 2008

Project Title:	
Performer:	
Presenter:	
Name of Peer Reviewer:	
Date of Review:	

The following pages contain the criteria used to evaluate each project. The criteria have been grouped into three (3) major categories: (1) Approach and Progress; (2) Project Merit; and (3) Deployment Considerations. Additionally, each criterion is accompanied by multiple characteristics to further define the topic.

The Reviewer is expected to provide a rating and substantive comments which support that rating for each criterion. Please note that if a rating of *"Results Not Demonstrated"* is selected, justifying comments must be included. To assist with determining the criterion rating, adjectival descriptions of those ratings are provided below.

RATING CRITERIA DEFINITIONS	
Effective	**Effective** projects set ambitious goals, achieve results, are well-managed and enhance the likelihood of meeting program goals and objectives.
Moderately Effective	In general, a project rated **Moderately Effective** has set ambitious goals and is well-managed, and is achieving results. Better results could be realized by focusing on key technical issues, more efficient use of resources, and improvements in overall management.
Adequate	**Adequate** describes a project that needs to set more ambitious goals, achieve better results, improve accountability or strengthen its management practices.
Ineffective	**Ineffective Projects** are unable to achieve results due to a lack of clarity regarding the project's purpose or goals, poor management, or some other significant weakness (e.g., technical problem).
Results Not Demonstrated	**Results Not Demonstrated** indicates that a project has not been able to develop acceptable performance goals or collect data to determine whether it is performing.

PEER REVIEW RATING CRITERIA

Please evaluate the project against each of the nine criterion listed below. Definitions for these nine criteria are provided on page 24. For each criterion, select the appropriate rating by typing an "X" in the applicable cell. Definitions for the five ratings criteria are provided on the previous page.

NOTE: If you rate any criterion as "Results Not Demonstrated," a justification for this rating is required. Please include your justification in the box at the end of this table.

CRITERION		RATING CRITERIA				
(Criteria Definitions, Refer to Page 24)		(Rating Criteria Definitions, Refer to Previous Page)				
		Results Not Demonstrated*	Ineffective	Adequate	Moderately Effective	Effective
APPROACH AND PROGRESS						
1	Existence of Clear, Measurable Milestones					
2	Rate of Progress					
3	Technical Approach					
4	Economic Analysis					
5	Utilization of Government Resources					
PROJECT MERIT						
6	Scientific and Technical Merit					
7	Anticipated Benefits, if Successful					
DEPLOYMENT CONSIDERATIONS						
8	Commercialization Potential					
9	Possible Adverse Effects Considered					
*Please explain why the project was rated "Results Not Demonstrated" for a particular criterion						

COMMENTS

Please provide your comments for each of the areas in the blocks below. Please substantiate your comments (i.e., facts on why you are making the statement). General statements without explanation (e.g., great project) are not sufficient. Please avoid any use of clichés, colloquialisms or slang.

Strengths:
Weaknesses:
Recommendations:
Action Item(s)
General Comments

CRITERION DEFINITIONS

APPROACH AND PROGRESS:

1: Existence of Clear, Measurable Milestones

- Milestones contained in the Statement of Project Objectives are indicated for each budget period.
- Milestones are quantitative and clearly show progression towards budget period and/or project goals.
- Each milestone has a title, planned completion date and a description of the method/process/measure used to verify completion.

2: Rate of Progress

- Progress to date against stated project goal, objectives, milestones, and schedule is reasonable.
- Continued progress against possible barriers is likely.
- There is a high likelihood project goal, objectives, and expected outcomes and benefits will be achieved.
- The budget is on track to achieve project goal and objectives.

3: Technical Approach

- Work plan is sound and supports stated project goal and objectives.
- A thorough understanding of potential technical challenges and technical barriers is evident.
- Effective methods to address potential technical uncertainties and barriers are presented.

4: Economic Analysis

- Thorough technology cost and performance assessments are conducted.
- Implementation cost estimates are sensible given uncertainties.
- There is a high likelihood of meeting ultimate DOE cost and performance goals.

5: Utilization of Government Resources

- Research team is adequate to address project goal and objectives.
- Sound rationale presented for teaming or collaborative efforts.
- Equipment, materials, and facilities are adequate to meet goals.

PROJECT MERIT:

6: Scientific and Technical Merit

- The underlying project concept is scientifically sound.
- Substantial progress or even a breakthrough is possible.
- A high degree of innovation is evident.

7: Anticipated Benefits, if Successful

- There exist clear statements of potential benefits if research is successful.
- Technologies being developed can benefit other programs.
- Project will make a significant contribution towards meeting near- and long-term program cost and performance goals.

DEPLOYMENT CONSIDERATIONS:

8: Commercialization Potential

- Researchers know and can describe a “real world” application and have completed appropriate market analyses.
- Market analyses indicate the technology being developed is likely to be implemented if research is successful.
- Potential barriers to commercialization have been identified and addressed.

9: Possible Adverse Effects Considered

- Potential adverse effects on the environment or public associated with widespread technology deployment have been considered.
- Scientific risks are within reasonable limits.
- Assessments of risk and suitable mitigation strategies have been considered.

APPENDIX E: FUEL CELL PROGRAM PROJECT SUMMARIES

Presentation ID Number	Project Number	Title
01	NT41837	Coal-Based Solid-Oxide Fuel Cell Power Plant Development
02	NT41246	Solid State Energy Conversion Alliance
03	NT42812	Santa Clara County California Solid-Oxide Fuel Cell Project
04	NT42613	Coal-Gas-Fueled SOFC Hybrid Power Systems with CO2 Separation
05	NT42810	Solid-Oxide Fuel Cell Technology Stationary Power Application Project (NC)
06	NT42614	Solid-Oxide Fuel Cell Coal-Based Power Systems
07	NT42513	Evaluation of a Functional Interconnect System for Solid-Oxide Fuel Cells
08	FEAA066	Reliability of Materials and Components for Solid-Oxide Fuel Cells
9	FWP40552	Low-Cost Modular SOFC Development—Refractory Glass
10	08-220621c	Coal-Based Fuel Cells—University Research Initiative Projects
11	FWP49071	Solid-Oxide Fuel Cell Research and Development—Synchrotron
12	MSD-NETL-01	Development of Inexpensive Metal Alloy Electrodes for Cost-Competitive Solid-Oxide Fuel Cells
13	NT41572	Functionally Graded Cathodes for Solid-Oxide Fuel Cells
14	NT42516	Development of Sulfur- and Carbon-Tolerant Reforming Alloy Catalysts Aided by Fundamental Atomistic Insight
15	FWP40552	Low-Cost Modular SOFC Development—Modeling
16	07-220611	Fuel Processing & Hydrogen Production
17	08-220621a	Coal-Based Fuel Cells—Contaminant Testing
18	NT41567	A Low-Cost Soft-Switched DC/DC Converter for Solid Oxide Fuel Cells

01: DE-FC26-04NT41837

Project Number DE-FC26-04NT41837	Project Title Coal-Based Solid-Oxide Fuel Cell Power Plant Development			
Contacts DOE/NETL Project Mgr.	Name Travis Shultz	Organization Power Systems Division	Email travis.shultz@netl.doe.gov	
Principal Investigator	Jody D. Doyon	Fuel Cell Energy, Inc.	jdoyon@fce.com	
Partners	Versa Power Systems; Gas Technology Institute; Pacific Northwest National Laboratory; Worley Parsons Group, Inc.; SatCon Power Systems, Inc.; Nexant, Inc.			
Stage of Development	_ Basic R&D	X Applied R&D	_ Proof of Concept	_ Demonstration

Technical Background:

Fuel Cell Energy Inc. (FCE) utilizes the planar cell and stack technology of its solid-oxide fuel cell (SOFC) provider, Versa Power Systems Inc. (VPS) for all of its SOFC development programs. FCE recently successfully completed a Solid State Energy Conversion Alliance (SECA) Phase I SOFC Cost Reduction Program to develop a 3-10 kW SOFC power plant system, demonstrating the VPS SOFC technology performance and cost. This VPS SOFC technology serves as the basis for further development and scale-up in this multi-MW, SECA Coal-Based Systems Phase I program. To date, VPS has successfully scaled up its manufacturing process from the baseline 156 cm^2 to over 1000 cm^2. Performance repeatability of scaled-up, 625 cm^2-size components (550 cm^2 active area) has been validated with several repeat single-cell and short-stack tests. For the coal-based multi-MW power plant, a cell size of 625 cm^2 and a stack building block size of 64 cells have been chosen, based on manufacturing and performance assessment, technical risk, and program requirements. Five of these stacks will be constructed into a 50-kW stack tower, and 20 stack tower units will be assembled into a single MW module that will serve as the basis for multi-MW power systems. This stack and module design configuration has undergone significant computational modeling analysis at FCE, VPS, and Pacific Northwest National Laboratory (PNNL).

Relationship to Program:

The development of SOFC technology will significantly advance the nation's energy security and independence interests, address pollution and greenhouse gas concerns, and help enhance the nation's economic growth.

Specific benefits to advancing SOFC technology for large scale, coal-based power generation include the following:

- Makes use of coal, the largest natural fuel source in the U.S. with an estimated 250 years of reserves
- Provides the highest power-plant efficiency with the lowest cost of electricity (COE)
- Has the lowest pollution emissions (NOx, SOx), as compared to conventional power generation technologies
- Addresses greenhouse gas concerns; enables simple power plant system design for carbon sequestration
- Enables power plant fuel tolerance to varying coal gasifier syngas compositions (hydrogen [H2], methane [CH_4], carbon monoxide [CO], carbon dioxide [CO_2])
- Enhances the nation's economic growth with domestic job creation and factory/equipment investment; the technologies developed under this DOE cooperative agreement require substantial manufacturing in the United States, thereby contributing to economic competitiveness

This project supports achievement of SECA Coal-Based System Development goals.

Primary Project Goal:

The objective of this program is to develop low-cost, high-performance solid-oxide fuel cell technology to support multi-MW coal-fueled central power systems. This three-phase program has the following supporting objectives:

- Resolve barrier issues concerning larger-size SOFCs and demonstrate an SOFC building block for multi-MW applications.
- Develop and optimize a design for a large scale (>100 MWe) baseline integrated gasifier fuel cell (IGFC) power plant incorporating an SOFC that will produce electrical power from coal. The system will be:
    - Highly efficient (>50% coal higher heating value [HHV])
    - Environmentally friendly (90% synthetic gas [syngas] CO_2 separation)
    - Cost-effective ($400/kWe, exclusive of coal gasification and CO_2 separation subsystems)
- Design, manufacture, and test a proof-of-concept system derived from the IGFC design.

Objectives:

Phase I of the project will focus on cell and stack development. This will include the scale-up of existing SOFC cell area and stack size (number of cells) and performance improvements. Preliminary engineering design and analysis for multi-MW power plant systems will also be conducted. Costs will be consistent with a projected cost of $600/kW for a multi-MW system. The Phase I deliverable will be demonstration of an SOFC stack building block unit that is representative of a MW class module on simulated coal syngas.

Phase II of the project will focus on modularization of the Phase I stack building block units into a MW-size module. Detailed design engineering and analysis for multi-MW power plant systems will also be conducted. The Phase II deliverable will be the test demonstration of a MW-size representative SOFC stack module on simulated coal syngas.

Phase III of the project will focus on the design and fabrication of a proof-of-concept multi-MW power plant. The Phase III deliverable will be tested for at least three years at FutureGen or another suitable SECA-selected site.

02: DE-FC26-02NT41246

Project Number DE-FC26-02NT41246	Project Title Solid State Energy Conversion Alliance			
Contacts DOE/NETL Project Mgr.	Name Heather Quedenfeld	Organization Power Systems Division	Email heather.quedenfeld@netl.doe.gov	
Principal Investigator	Steven R. Shaffer	Delphi Corporation	steven.shaffer@delphi.com	
Partners	Battelle Memorial Institute Pacific Northwest Division United Technologies Research Center Electricore Inc.			
Stage of Development	_ Basic R&D	_X_ Applied R&D	_ Proof of Concept	_ Demonstration

Technical Background:

Delphi views solid-oxide fuel cells (SOFCs) as a highly competitive power source for stationary and mobile applications, and as a device with high potential efficiencies, low emissions, and low noise. Pursuing the high-volume transportation market will provide the drive for stack and balance-of-plant designs that will meet SECA's goals and facilitate volume production of SOFC systems. The reformer is the only major component that must be designed for the specific fuel, with other components being common across applications. The project approach is to pursue transportation auxiliary power units while simultaneously developing configurations for stationary distributed power generation using natural gas. This project focuses on key items that require "breakthrough" developments to achieve the SECA goals. The targets for performance and cost will meet or exceed those defined as the minimum goals for the three phases of SECA.

Relationship to Program:

This project focuses on key items that require "breakthrough" developments to achieve the SECA goals. This project will provide SOFC technology that will be a cost-competitive product for transportation and stationary markets. The basic cell and stack technology will be applicable to systems ranging from 3 kW to hundreds of megawatts. The technology will benefit the nation in producing power more efficiently and providing a benefit to the Department of Defense.

Primary Project Goal:

The primary goal of this project is to develop a cost-effective SOFC technology that is applicable to stationary and transportation applications.

Objectives:

The following information details the objective for each main area of development:

System design and integration. Integrating the required components into efficient, reliable, safe, and cost-effective modular SOFC systems is a complex task. All applications will require integration of the SOFC stack and reformer with the appropriate controls, safety systems, heat recovery, thermal management and insulation, enclosure and packaging, air-delivery system (including blower), fuel-delivery system (including pump), and exhaust system.

SOFC stack. The SOFC stack is the primary component that has required fundamental research and development. The major technical challenges in developing a cost-effective, efficient, and reliable planar SOFC stack are developing robust, cost-effective cells and interconnects with compatible, stable hermetic seals that are durable and reliable with thermal cycling.

Reformer. The two reformers being developed during this program are catalytic partial oxidation (CPOx) and endothermic (steam) reformers. Avoidance of coking (i.e., fouling of the catalyst with solid carbon) during all phases of operation is a major technical challenge for both of these reformers. Rapid start-up is important for reformer robustness because the reformer catalysts are prone to coking in a slow or poorly controlled start-up. Coking is always a risk, especially because efficiency demands that the reformer be operated close to the sooting limit. Sulfur, present in all commercial fuels in a variety of chemical forms and concentrations, also imposes a major technical challenge. If the sulfur tolerance of reforming catalysts and the SOFC anode cannot be improved, then reliable, cost-effective means of desulfurization will be developed.

Balance of plant. Although the components that comprise the balance of plant do not present as high a level of technical challenge as do system integration, stack, and reformers, considerable engineering development is required to bring these components to the required level of performance and cost.

03: DE-FC26-06NT42812

Project Number DE-FC26-06NT42812	Project Title Santa Clara County California Solid-Oxide Fuel Cell Project			
Contacts DOE/NETL Project Mgr.	Name Charles T. Alsup	Organization Power Systems Division	Email charles.alsup@netl.doe.gov	
Principal Investigator	Caroline Judy	Santa Clara County California	caroline.Judy@faf.sccgov.org	
Partners	Bloom Energy			
Stage of Development	__ Basic R&D	__ Applied R&D	__ Proof of Concept	X Demonstration

Technical Background:

This project is being developed through the Board of Supervisors initiative to promote fuel cells; one of the five initiative objectives is to establish a stationary fuel cell power generation system. The project was competitively bid to Bloom Energy, which elected to provide a minimum 15-kW planar solid-oxide fuel cell (SOFC) stationary power generation system for the County Communications 911 Headquarters. The site demands a highly reliable power source for 24/7 operations and has relatively stable loads; the peak load is approximately 122 kW. The project is building a planar SOFC system for stationary power generation. Planar solid-oxide uses electrochemical conversion through a ceramic electrolyte to produce electricity directly from a given fuel source. Like other fuel cell technologies, planar SOFCs are highly efficient and reliable compared to other types of electricity generators. The system will demonstrate input fuel flexibility (including natural gas and ethanol), and work to increase permitting authorities' (e.g., fire marshal, building inspector) familiarity with planar SOFC technology. The system fits on a concrete pad of 24 ft. by 22 ft. and has a:

- Target reliability of 99% electrical availability
- Target electrical efficiency of 45% (Lower heating value [LHV] net AC) over a 8,760-hour demonstration
- Target to reduce SOx, NOx, and particulate emissions to California Air Resources Board (CARB) 2007 standards.

Relationship to Program:

This project provides an important field demonstration of a stationary fuel cell power generation system that will offer input fuel flexibility, high reliability, and emissions reductions that meet CARB 2007 standards.

The project will improve local government awareness of fuel cells. It will also pave the way for local permitting and approval of planar SOFC projects in other jurisdictions by establishing a methodology for local government building inspectors and the fire marshal to review and approve stationary fuel cell systems.

Primary Project Goal:

Demonstrate planar SOFC power generation system technology at a county-owned site within Santa Clara County, California.

Objectives:

The objectives of this project are to:

- Operate system at peak efficiency for one year demonstration
- Demonstrate input fuel flexibility through operating using ethanol for a period of one month
- Provide a reliable, efficient, and cleaner source of power
- Meet educational objectives of the Board of Supervisors

04: DE-FC26-05NT42613

Project Number DE-FC26-05NT42613	Project Title Coal-Gas-Fueled SOFC Hybrid Power Systems with CO_2 Separation			
Contacts DOE/NETL Project Mgr.	Name Travis Shultz	Organization Power Systems Division	Email travis.shultz@netl.doe.gov	
Principal Investigator	Joseph F. Pierre	Siemens Power Generation	joseph.pierre@siemens.com	
Partners	None			
Stage of Development	_ Basic R&D	X Applied R&D	_ Proof of Concept	_ Demonstration

Technical Background:

The program will adapt technology developed and incorporate lessons learned by Siemens from its prior solid-oxide fuel cell (SOFC) technology development programs. Siemens is the recognized world leader in SOFC technology, and its SOFCs have operated for more than 69,000 hours with minimal degradation, and have been subjected to more than 100 thermal cycles with no deleterious effects. Its fully integrated SOFC power systems have operated for more than 36,000 hours with no measurable degradation. Siemens, through its gasification, gas turbine, and stationary fuel cell businesses, is uniquely positioned to satisfy the goals and objectives of this program.

Relationship to Program:

Reliable, high-efficiency SOFC systems fueled by coal permit the capture of CO_2, a key greenhouse gas (GHG), while providing electricity at a cost that is competitive with today's power-generation technologies. In addition, these systems produce little or no NO_x or SO_x, (< 0.5 parts per million by volume [ppmv]). This project supports achievement of SECA Coal-Based System Development goals.

Primary Project Goal:

The objective of this program is to develop low-cost, high-performance SOFC technology to support multi-MW coal-fueled central power systems. This three-phase program has the following supporting objectives:

- Resolve barrier issues concerning larger-size SOFCs and demonstrate an SOFC building block for multi-MW applications.
- Develop and optimize a design for a large-scale (>100 MWe) baseline integrated gasifier fuel cell (IGFC) power plant incorporating an SOFC that will produce electrical power from coal. The system will be:
    - Highly efficient (>50% coal higher heating value [HHV])
    - Environmentally friendly (90% synthetic gas [syngas] CO_2 separation)
    - Cost-effective ($400/kWe, exclusive of coal gasification and CO_2 separation subsystems)
- Design, manufacture, and test a proof-of-concept system derived from the IGFC design.

Objectives:

The Phase I project objectives are:

- The creation of a conceptual design and the performance of a feasibility analysis of the selected cycle for both the baseline plant and proof-of concept demonstration system
- The analysis, design optimization, and scale-up of the Siemens delta-N cell to its largest practical size
- The design, building, and testing of simulated coal-gas of a thermally self-sustaining fuel cell stack
- A cost analysis showing that the baseline system power block cost will not exceed $600/kWe at a determined production volume

05: DE-FC26-06NT42810

Project Number DE-FC26-06NT42810	Project Title Solid-Oxide Fuel Cell Technology Stationary Power Application Project (NC)			
Contacts DOE/NETL Project Mgr.	Name Travis Shultz	Organization Power Systems Division	Email travis.shultz@netl.doe.gov	
Principal Investigator	Joseph F. Pierre	Siemens Power Generation	joseph.pierre@siemens.com	
Partners	Phipps Conservatory and Botanical Gardens, Pittsburgh, PA			
Stage of Development	_ Basic R&D	X Applied R&D	X Proof of Concept	X Demonstration

Technical Background:

Siemens' solid-oxide fuel cell (SOFC) utilizes a composite interlayer (CIL) between the air electrode and electrolyte to reduce cell area specific resistance (ASR), resulting in an increase in power density under equivalent operating conditions. The importance of this cell feature has been successfully and repeatedly demonstrated in many single-cell tests. Additional success in a two-bundle (48 cell total) test further advanced this technology from a laboratory scale to a pre-production mode. The recent two-bundle test incorporating a CIL was the first SOFC generator to deliver electrical power greater than its nominal rating. Assuming a cost-effective technique for applying the CIL to a substrate, the economics of an SOFC power system can be improved commensurate with the increase in cell power. The use of the composite interlayer and advanced electrolyte material may generate a 15–27% power enhancement, depending on the operating temperature.

One objective of this project is to develop efficient processes to apply the interlayer to SOFC substrates. These processes will be suitable for mass production. Utilizing lessons learned from the interlayer implementation program designed for tubular cells, application techniques shall be evaluated based on their adaptabilities to solid oxide fuel cells with high power density (HPD). The development of a cost-effective and production-friendly interlayer application technique would facilitate the commercialization of SOFC power systems.

Two processes have been evaluated: rolling and dip coating. In the roller technique, delta-8 substrates survived the coating process with no visible structural damage. This observation showed that the mechanical stress generated during the coating process was very low. Secondly, all these sections reached the target weight pickup range with a very tight distribution, indicating that an excellent control of CIL weight could be achieved by this process. However, the semi-automated process of rolling a CIL onto a substrate depends on the shape and dimensions of the substrate. That is, when the roller encounters peaks or valleys, the application may be incomplete.

A dip-coating process is generally insensitive to the shape and dimensions of the substrate. This dip-coating system was designed and built in house with the capability of coating both the tubular and delta-8 substrates. After the slurry composition was tailored, CIL was successfully and reproducibly applied onto tubular substrates, and the cell performance favorably reached the target range. The recent attempts to dip coat the delta-8 substrate also showed very encouraging results, including the anticipated 100% coverage and limited peak-to-valley and end-to-end thickness variations. Although the throughput of the dip-coating process is estimated to be at least an order of magnitude lower than that of the roller-coating process, its development will be continued as a backup process in case the aforementioned surface-coverage issue cannot be readily resolved.

Formal demonstration of the interlayer-enhanced fuel cell is underway. In the second quarter of 2007, Siemens completed site installation and start-up of a 5-kWe SOFC system at the Phipps Conservancy and Botanical Gardens in Pittsburgh, PA. In the first quarter of 2008, Siemens completed a SECA HPD cell test and evaluation.

Relationship to Program:

The development of a cost-effective and production-friendly interlayer application technique would facilitate the commercialization of SOFC power systems. The use of the composite interlayer and advanced electrolyte material may generate a 15–27% power enhancement, depending on the operating temperature. Testing will demonstrate capability to meet SECA targeted degradation rates for SOFC systems.

Primary Project Goal:

The power enhancement achieved by the composite interlayer can be further promoted by using the optimal cell geometry, which maximizes the power-to-volume ratio. The primary goal of this program is to accelerate the development of an interlayer application technique that is suitable for HPD cells. Candidate application techniques will be evaluated and a preferred technique shall be selected based on its cost effectiveness and readiness. Secondly, two 5-kWe SOFC systems will be built and operated for the purpose of evaluating cell and bundle techniques, advanced generator and module design features, and cost-reduction initiatives.

Objectives:

The objectives of this project are:

- To develop a reliable, cost-effective and production-friendly technique to apply the power-enhancing layer at the interface of the air electrode and electrolyte of high power density solid-oxide fuel cells
- To design, build, install, and evaluate operation in the state of North Carolina of a 5-kWe SOFC system that incorporates advanced module features
- To design, build, and evaluate operation of a state-of-the-art 5-kWe SOFC system in the Phipps Conservatory and Botanical Garden

06: DE-FC26-05NT42614

Project Number DE-FC26-05NT42614	Project Title Solid-Oxide Fuel Cell Coal-Based Power Systems			
Contacts DOE/NETL Project Mgr.	Name Travis Shultz	Organization DOE-NETL	Email travis.shultz@netl.doe.gov	
Principal Investigator	Matthew Alinger	GE Global Research	alinger@research.ge.com	
Partners	Pacific Northwest National Laboratory, Richland, WA			
Stage of Development	_ Basic R&D	X Applied R&D	_ Proof of Concept	_ Demonstration

Technical Background:

GE performed a risk assessment of the solid-oxide fuel cell (SOFC) program in Q4 2006, identifying performance degradation and the impact on the cost model assumptions as the greatest risks to SOFC commercialization. Therefore, this program is tailored to identification and mitigation of the key factors affecting SOFC performance degradation for cells in contact with metallic interconnects. A fundamental understanding of associated mechanisms is being developed using a fixed materials set, based on cells with yttria-stabilized zirconia (YSZ) electrolytes and lanthanum strontium cobalt ferrite (LSCF) cathodes for operation at ~800 °C.

Relationship to Program:

By providing solutions to mitigate performance degradation, this project will enable a path to commercial realization of SOFCs. LSCF cathode-based SOFCs enable the power densities required to meet SECA cost targets, but currently suffer from higher degradation rates than lanthanum strontium manganite (LSM)/YSZ cells. In addition, understanding the upper specification limit for silicon in the interconnect alloy will allow evaluation of paths to commercial interconnect processing and chemistries.

Primary Project Goal:

The primary goal of this project is to identify the dominant SOFC performance degradation mechanisms in high-performance SOFCs (>0.75 W/cm^2) and to develop and implement mitigation strategies in order to retain high electrochemical performance (<1% power density loss/1000h) between 750–850 °C.

Objectives:

The objectives of this project are to identify key factors affecting SOFC performance degradation for cells in contact with metallic interconnects, develop corresponding mitigation strategies, and evaluate and down-select strategies to meet target degradation rates. Mechanism identification is studied on a fixed materials set. Interfacial microstructural and elemental changes are characterized, and their relationships to observed degradation are identified. Focus is on microstructural stabilization and minimization of the area specific resistance (ASR) contribution from chromia and silica scale growth on the interconnect, in addition to interactions at electrode/interconnect interfaces evaluated during electrochemical testing and subsequent advanced microstructural characterization. Novel long-term testing techniques are used and conducted under standard operating conditions to demonstrate capability to meet targeted degradation rates.

07: DE-FC26-05NT42513

Project Number DE-FC26-05NT42513	Project Title Evaluation of a Functional Interconnect System for Solid-Oxide Fuel Cells			
Contacts DOE/NETL Project Mgr.	Name Ayyakkannu Manivannan	Organization Power Systems Division	Email ayyakkannu.manivannan @netl.doe.gov	
Principal Investigator	James Rakowski	Allegheny Technologies	jrakowski@allegenyludlum.com	
Partners	Pacific Northwest National Laboratory (informal working relationship)			
Stage of Development	_ Basic R&D	_X_ Applied R&D	_ Proof of Concept	_ Demonstration

Technical Background:

Ferritic stainless steels are candidates for solid-oxide fuel cell (SOFC) interconnects due to thermomechanical compatibility with the active fuel cell components and overall oxidation resistance. Such steels exhibit acceptable oxidation resistance and form chromium oxide surface layers, which have a good combination of growth rate and intrinsic electrical conductivity. Several issues remain to be solved, including the elimination/mitigation of chromium evolution and fuel cell poisoning, reduction in area specific resistance (ASR) increase due to general oxidation, and elimination/mitigation of the formation of resistive silica phases at the scale/alloy interface. Considerable progress has been made to identify alloys that exhibit significant oxidation resistance at both the lower and upper temperature regimes typical of planar SOFC operation. The issue of silica formation has been addressed by the development of a silicon removal process, which acts on the solid-state material, rather than via specialized melt processing. The addition of niobium index (Nb), a common alloying agent in ferritic stainless steels, has also been shown to aggregate silicon from the metal during high-temperature exposure.

Relationship to Program:

This project supports vital materials and manufacturing advances within the Solid State Energy Conversion Alliance (SECA) Core Technology Program. The project should identify a range of options for interconnect solutions that provide the required performance at a given cost level. The project is focused on technology that can be readily implemented into current SOFC applications.

Primary Project Goal:

The primary goal is to develop technologies for implementation of metallic interconnects for planar SOFCs. These should result in low absolute cost per part, a good cost/performance ratio, and compatibility with high-throughput manufacturing processes.

Objectives:

Project objectives are to:

- Acquire commercially available stainless steels for testing
- Develop and melt commercially viable compositions for novel stainless steels
- Prepare desiliconized test panels from the two above objectives.
- Test and verify concepts via high-temperature oxidation testing and long-term ASR evaluation, including treated and coated samples
- Deliver a range of solutions for planar SOFC interconnects

08: FEAA066

Project Number FEAA066	Project Title Reliability of Materials and Components for Solid-Oxide Fuel Cells - ORNL			
Contacts DOE/NETL Project Mgr.	Name Travis Shultz	Organization Power Systems Division	Email travis.schultz@netl.doe.gov	
Principal Investigator	Edgar Lara-Curzio	Oak Ridge National Laboratory (ORNL)	laracurzioe@ornl.gov	
Partners				
Stage of Development	X Basic R&D	_ Applied R&D	_ Proof of Concept	_ Demonstration

Technical Background:

To ensure optimum performance, durability, and reliability, solid-oxide fuel cell (SOFC) designers need to be aware of the innate features of the ceramic materials they incorporate into their designs. Currently, to minimize ohmic losses, most SOFC designs are based on the use of electrolytes that are on the order of ten microns thick, at which point the electrolyte can no longer be self-supporting. As a result, manufacturing techniques involve the engineering of multilayer anode/electrolyte/cathode assemblies to provide the required structural support. Because predictions of service life and reliability of SOFCs require a fundamental understanding of damage initiation and progression in cell components, the evaluation of multilayer anode/electrolyte/cathode cells provides a realistic scenario for studying the effect of processing and fabrication parameters and residual stresses on damage initiation and progression in these materials.

An important SOFC design issue currently being addressed is the steady-state performance degradation (decreases in cell voltage with time) exhibited by some planar SOFCs. This degradation has been attributed to mechanisms that occur on the cathode side of the cell, including interactions between the cathode and the metallic interconnect material. Metallic interconnects used in state-of-the-art planar SOFCs have the advantage of higher electronic and thermal conductivity, higher ductility, and better workability, as well as substantially lower cost. However, at the typical planar SOFC operating temperatures (650-850 °C), design requirements for metallic interconnects are challenging because they must maintain low contact resistance (requiring chemical stability and uniform contact, usually requiring some pressure) with the cathode.

To reduce interfacial resistance, contact aids (layers) are often applied between the cathode and the metallic interconnect during the assembly of SOFC stacks. The contact material must be chemically compatible in oxidizing conditions with both the interconnect material and the cathode because reactions could result in the formation of phases that could lead to an increase in contact resistance or thermal expansion mismatches, which could lead to delamination. It is common to sinter the contact layer during the first heating cycle of the stack, in which case it is important that the contact material possesses appropriate sintering activity to provide sufficient interfacial and bulk contact and strength. The maximum temperature for this step is limited in order to prevent adverse material interactions elsewhere within the cell, including cathode/electrolyte interactions and excessive oxidation/damage to the metallic interconnect. Typical contact materials such as lanthanum strontium manganite (LSM) do not sinter well at these reduced temperatures, and are consequently very susceptible to delamination and bulk fracture.

Relationship to Program:

This project supports vital materials and manufacturing advances within the Solid State Energy Conversion Alliance (SECA) Core Technology Program.

Studies of the relationships among processing, microstructure, and properties of materials for solid oxide fuel cells will enable materials scientists and engineers to develop materials with the properties required to ensure durable, reliable, and optimum performance. The results of these studies have been compiled in databases that allow designers to use modeling tools to predict the behavior and performance of these systems as a function of key material properties. This, in turn, will reduce design-cycle times.

Primary Project Goal:

The overarching goal of this project is to identify the mechanisms that are responsible for the failure of SOFC materials and components—in particular multilayer anode/electrolyte/cathode assemblies, which constitute the building blocks of these systems—and to use that information to support the development and implementation of probabilistic design methodology for predicting the life of SOFCs.

Objectives:

For the performing period associated with FY08, one objective of the project is to identify and utilize test techniques to determine the physical and mechanical properties of state-of-the-art cathode contact paste materials, as well as the mechanical properties of the interfaces that exist between the cathode and the contact paste and between the contact paste and metallic interconnects or coated metallic interconnects. The properties obtained will support ongoing efforts within the SECA Core Technology Program to develop models of the thermomechanical and electrochemical behavior of SOFCs. This study will also provide insight into the mechanisms responsible for the degradation of SOFCs and, in turn, strategies to overcome these limitations, particularly when SOFCs are subjected to service conditions for long periods of time, including cyclic operation.

Another objective of the project for FY08 is to contribute, in collaboration with researchers from PNNL, to the development of a design guide for solid-oxide fuel cells. This activity is being coordinated by the American Society of Mechanical Engineers (ASME) Standards Technology, LLC. The objective of the guide is to provide recommended probabilistic and reliability-based design practices and associated modeling and analysis procedures, to be used by U.S. designers and fabricators of SOFCs, to optimize design of durable and reliable SOFCs. The guide is based on reliability theory and will describe suggested analytical procedures developed by the SECA Core Technology Program to model electrochemical and thermomechanical performance of SOFCs, as well as how these tools and other simulation tools can be used in designing a structurally reliable and durable SOFC stack.

09: FWP-40552

Project Number FWP-40552	Project Title Low-Cost Modular SOFC Development—REFRACTORY GLASS			
Contacts DOE/NETL Project Mgr.	Name Ayyakkannu Manivannan	Organization Power Systems Division	Email ayyakkannu.manivannan@netl.doe.gov	
Principal Investigator	Matt Chou	Pacific Northwest National Laboratory (PNNL)	yeong-shyung.chou@pnl.gov	
Partners	None			
Stage of Development	_ Basic R&D	X Applied R&D	_ Proof of Concept	_ Demonstration

Technical Background:

Planar solid-oxide fuel cell (SOFC) stacks require adequate seals between interconnects and adjacent cell components in order to prevent mixing of the oxidant and fuel gases within the stack and leakage of the gas streams from the stack. Several different approaches to sealing SOFC stacks are available, including rigid, bonded seals (e.g., devitrifying glass), compliant seals (e.g., viscous glass), and compressive seals (e.g., mica-based "gaskets"). Glass-based seals typically soften and flow slightly during stack fabrication (at a temperature above the operating temperature) but then become rigid and immobile through devitrification (to avoid excessive flow or creep) at the stack operating temperature.

Devitrifying glass seals represent a relatively easy means of sealing an SOFC stack (at least initially), but they face challenges in meeting the stringent SOFC requirements, including long-term operation at elevated temperatures and thermal cycling between operating and room temperatures. For example, the coefficient of thermal expansion (CTE) of the seals must be closely matched to the other stack components in order to avoid buildup of stresses during thermal cycling. Without a good CTE match, the seal can fracture during repeated thermal cycling, leading to stack failure due to gas intermixing and hot spot formation. Interconnects and cell frames are typically made from ferritic stainless steels with an average CTE (RT to 800 ºC) of ~12.5-13 ppm/ºC. Typical anode-supported cells have a similar CTE of ~12.5 ppm/ºC. While glass compositions can be tailored to optimize their physical properties, the selection of glasses offering appropriate thermal expansion behavior is relatively narrow. The selection of sealing glass compositions is further limited by the need for the glass to have appropriate wetting behavior and viscosity at the sealing temperature. In addition, since most SOFC sealing glasses devitrify at stack operating temperatures, the seals experience significant microstructural and crystalline phase changes over time. Thus, control of the devitrification kinetics and phases is required to ensure that the long-term CTE of the seal remains compatible with other stack components. Chemical compatibility with the stack components and the gaseous constituents of the highly oxidizing and reducing environments are also of primary concern. Glasses can potentially interact with other stack components, such as interconnects, electrolytes, or electrodes, at SOFC operating temperatures. Interactions can occur over a short range (e.g., via direct physical contact) or over longer distances (via gaseous transport of species to or from the glass).

Another key requirement to making glass-ceramic sealants viable as a long-term sealing solution for SOFCs is to control their reactivity with the metal components such as interconnects. For example, alkaline earth-containing aluminosilicate glass sealants generally adhere well to yttria-stabilized zirconia (YSZ) electrolyte with little chemical interaction, but they tend to form interfacial reaction products such as barium or strontium chromate when bonded to candidate stainless steel interconnects. During long-term exposure at the stack operating temperature, growth of these high CTE (~22 ppm/ºC) phases can significantly degrade interfacial strength, leading to seal failure. Interactions with the SOFC gases can also potentially compromise the bulk seal itself, both in terms of strength and/or hermeticity, through erosion of seal material. Minimizing the amount of volatile constituents and/or minimizing the exposed seal surface area may be required for long-term seal stability.

Most SOFC sealing glasses are designed to seal at temperatures fairly close to stack operating conditions. For example, PNNL's "G18" sealing glass (a barium/calcium aluminosilicate glass with boron additions), which was developed for sealing planar stacks operating at ~700–800 ºC, has a sealing temperature of ~830 ºC. During operation, the glass undergoes substantial crystallization but still contains an appreciable amount of reactive (high boria content) residual glass. Also, the CTE of the G18 decreases as devitrification proceeds.

In response to these issues, de-vitrifying "refractory" glass seals, which are sealed at relatively high temperatures (>900 ºC), are under development at PNNL. Refractory sealing glasses potentially offer improved stability in terms of thermal expansion, chemical compatibility, interfacial strength, and minimal interfacial reactivity during long-term operations. In addition, the higher stack fabrication temperature may result in increased strength and electrical conductivity of contact materials at the cathode/interconnect contact zones. In previous work (FY05–FY07), optimized "refractory" sealing glass compositions in the strontium-calcium-yttrium-boron-silicon-oxygen (Sr-Ca-Y-B-Si-O) system were developed, which exhibit stable CTEs in the desired range of 11.5–12.5 ppm/ºC and sealing temperatures in the 950–1000 ºC range. Weight loss measurements indicated that the total material loss through vaporization should be minimal (~0.1 wt%) during stack lifetime. Electrical resistance tests of sealed interconnect alloy coupons demonstrated very high electrical resistance (under DC loading in SOFC operating conditions), which remained stable for over 1,000 hours.

However, similar to other sealing glasses such as G18, microstructure analysis did reveal a tendency to form alkaline earth chromate (in this case, $SrCrO4$) at the glass/interconnect interfaces in the oxidant gas. As noted above, the formation of alkaline earth chromates at seal-to-alloy interfaces must be mitigated due to their high CTE, which can lead to reduced interfacial strength due to large residual stresses. Mechanical testing of the seal/joint strengths of glass-sealed alloy coupons confirmed the degradation in tensile strength during high-temperature exposure to air, due to the formation of interfacial strontium chromate.

Based on these results, PNNL began investigating alloy surface modifications intended to stabilize the seal/interconnect interface by preventing the formation of the chromate phase. One of the mitigation approaches involves the formation of an aluminum oxide layer on the alloy surface, which may offer a means of preventing chromium oxide-containing scale on the iron-chromium (Fe-Cr) steel from contacting, and subsequently reacting with, alkaline earth constituents (e.g., Sr) in the glass seal material.

PNNL has a wide range of characterization techniques (e.g., x-ray diffraction [XRD], scanning electron microscopy [SEM], energy dispersive spectrometry [EDS], transmission electron microscopy [TEM], x-ray photoelectron spectrometry [XPS], thermogravimetric analysis [TGA], differential scanning calorimetry [DSC], particle size analysis [PSA], dilatometry, conductivity, single and dual atmosphere oxidation) and multiple component performance tests (e.g., button cell, interconnect/electrode area specific resistance [ASR], and seal leak tests) available for structural, chemical, and electrical characterization of SOFC component materials. However, given the complexity and variety of materials utilized in SOFC stacks, it is important to test the performance of various components not only individually but also in a representative stack environment. Such tests are very challenging, due to the presence of multiple components and conditions, which can result in complex inter-component interactions. However, they also offer a higher degree of relevance to the cells and stacks being developed by SECA industrial teams. In other words, a stack test fixture can help bridge the gap between small-scale tests, such as button cells, and the full-size cells and stacks under development by industrial developers. In response to this need, PNNL is participating in the development and implementation of a SECA Core Technology Program stack test fixture intended for the testing and validation of newly developed SOFC materials, processes, and design concepts. Materials to be evaluated may include sealing materials, protective interconnect coatings, interconnect alloys, contact materials, new cathode or anode materials, and commercial cells from SOFC manufacturers.

PNNL has modified an initial test fixture design (provided by Lawrence Berkeley National Laboratory [LBNL]) to include a cell-in-frame component to allow for simultaneous testing of cell-to-frame and stack perimeter seals. Cathode and anode flow fields are also being modified to more closely simulate full-size stack designs. Components of the test fixture are fabricated at PNNL, and tests are performed in dedicated test stands. Electrochemical performance of the stacks is measured under isothermal and/or thermal cyclic conditions. Once the tests are complete, the stack components are analyzed by appropriate characterization techniques as described above. Results from the stack tests are compared to results obtained from testing of individual components and sub-stack structures to evaluate effects of stack geometry and inter-component reactions on performance. PNNL's refractory glass seals are among the recently developed materials being evaluated in the fixture.

Relationship to Program:

This project supports vital materials and manufacturing advances within the SECA Core Technology Program. Leak-tight sealing of planar SOFC stacks is generally acknowledged to be a significant challenge facing SOFC developers. In addition to preventing leakage of gases from the stack as well as mixing of oxidant and fuel gases within the stack over the long stack operating lifetime, the seals must also allow the stack to be thermally cycled between ambient conditions and relatively high operating temperatures (e.g., 800 ºC). The successful development and transfer of inexpensive, reliable stack-sealing technology will assist SECA industrial developers in designing and manufacturing SOFC stacks that meet the aggressive SECA cost and performance targets.

Primary Project Goal:

The goal of the specific project task under review, Refractory Glass Seals, is to develop cost-effective seals and seal/interconnect interfaces with stable thermal, mechanical, electrical, and chemical properties during long-term SOFC operation.

Objectives:

The objectives of this project task are to: (a) develop de-vitrifying sealing glass compositions that offer improved thermal stability and higher sealing temperatures than conventionally used SOFC sealing glasses, (b) evaluate thermal, electrical, and mechanical properties of the seals based on the new glass formulations, (c) mitigate chemical instability/reactivity at glass/component interfaces through interfacial modifications, and (d) evaluate sealing glass performance under SOFC stack operating conditions.

10: ORD-08-220621C

Project Number 11: ORD-08-220621c	Project Title Coal-Based Fuel Cells – University Research Initiative Projects			
Contacts DOE/NETL Project Mgr.	Name Dan Maloney	Organization Energy Systems Dynamics Division	Email daniel.maloney@netl.doe.gov	
Principal Investigator	Randy Gemmen	Energy Systems Dynamics Division	randy.gemmen@netl.doe.gov	
Partners	Christopher Matranga, Chemistry and Surface Science Division, NETL Yves Mants, Chemistry and Surface Science Division, NETL John Kitchin, Dept. of Chemical Engineering, Carnegie Mellon Univ. Paul Salvador, Dept. of Materials Engineering, Carnegie Mellon Univ. Sridhar Seetharaman, Dept. of Materials Engineering, Carnegie Mellon Univ.			
Stage of Development	_X_ Basic R&D	_Applied R&D	_Proof of Concept	_Demonstration

Technical Background:

Solid-oxide fuel cells (SOFCs) are electrochemical conversion devices (converting chemical energy stored in fuels to electrical energy in a highly efficient process) that can operate off of a variety of fuels, including fossil fuels such as coal, owing to their high (600–900 °C) operating temperatures. Two major issues with cathodes in SOFCs are (1) the reactivity of a given material system for the oxygen reduction reaction, which directly affects the maximum efficiency of the process, and (2) the degradation of a given materials system during operation of the SOFC, which directly affects both the instantaneous efficiency and the overall lifetime of the devices. The two University Research Initiative Projects described herein (which are in the area of coal-based fuel cells) are fundamental projects that aim to generate a basic understanding of the factors that control both the reactivity and degradation of SOFC cathodes.

Project 1: In-Situ Spectroscopy on SOFC Cathode Materials

The rational design of new, superior cathode materials for SOFCs is hindered by the present lack of molecular understanding of the oxygen reduction mechanism. In this regard, surface-specific analytical techniques will be used to study oxygen interactions with common cathode materials, like $(La,Sr)MnO_3$ (LSM). The key information we need are the identities of oxygenated species on the cathode surface. These identities will help clarify the molecular processes that occur at the cathode at reaction conditions. In this regard, Raman spectroscopy has been previously used to characterize oxide materials and their interactions with oxygen as well as SOFC materials under potential control. Infrared emission has also been previously used to characterize the cathode/gas interface at high temperatures and under potential control. Our research will build off of this small body of earlier successes. We will initially use Raman and infrared emission to conduct in-situ measurements of oxygen interacting with high surface area LSM and yttria-stablized zirconia (YSZ, which is commonly used in composite LSM-YSZ cathodes) powders at different temperatures and pressures of oxygen as well as electrochemical potentials (at a later time). These spectroscopies will identify the peroxide, superoxide, and molecular oxygen species present on the cathode surface. They will also elucidate how temperature cycling and exposure to various gases alters the concentration of each of these species.

Project 2: Studies on the Evolution of Crystallographic Nature of Cathode Microstructural Features in SOFC in Operating Conditions

All components inside SOFCs—the cathode, anode, electrolyte, and interconnect—have complex microstructures that evolve under the aggressive SOFC operating conditions (elevated temperatures, oxidizing/reducing environments, and electrochemical loading). Importantly, both the activity and the long-term degradation of fuel cells are linked to the detailed features of the microstructure. Unfortunately, very little is known about the crystallographic nature (or its evolution) of the active microstructural features, such as interfaces and triple-phase boundaries in the electrodes. We will develop the experimental protocols to determine the crystallographic nature of the interfaces and triple-phase boundaries in SOFCs, and establish a basic understanding of the factors that determine their populations and evolution.

Relationship to Program:

These projects support vital cathode performance advances within the Solid State Energy Conversion Alliance (SECA) Core Technology Program.

Project 1: In-Situ Spectroscopy on SOFC Cathode Materials
This project offers multiple benefits aligning with SECA goals, including:

- A better understanding of how oxygen interacts with cathode surfaces and how this interaction may be affecting SOFC performance.
- A quantitative picture of how much of each type of oxygen species is present on a cathode surface at a given temperature and gas composition.
- Synthesis of new, high surface area, SOFC materials for lab-based investigations, which can be extended in future work toward electrode microstructural investigations.
- A direct correlation between computational chemistry studies, experiments on high surface area powders, and on well-defined epitaxially grown thin films, which will allow computational researchers to develop better models for predicting new SOFC cathode materials.

Understanding O_2 surface chemistry will guide new cathode development. Better cathodes will help meet DOE goals of higher cell voltages and efficiencies of greater than 50%. Surface chemistry approach can directly test computational chemistry predictions for cathode materials. Surface techniques can be applied to a range of SOFC, catalysis, and materials problems.

Project 2: Studies on the Evolution of Crystallographic Nature of Cathode Microstructural Features in SOFC in Operating Conditions
This project will develop the following:

- A basic understanding of the interfacial (grain boundary, solid-phase boundary, and surface) populations and energies of YSZ and LSM, as a function of thermal and electrochemical loads.
- A quantitative understanding of the crystallographic nature of the cathode microstructure, including the grain boundary structure, surface orientations, and two-phase and triple-phase boundary structure.
- A relation between the processing history and performance to the crystallographic nature of the microstructural features of the SOFC cathode.

The newly gained understanding will guide development of new engineered surfaces and materials having improved oxygen reactivity, which will result in both higher cell voltage and fuel cell efficiency to support the SECA program.

Primary Project Goal:

The primary goal for Project 1 is to conduct experiments to achieve a better understanding of the oxygen species present on cathode surfaces and the (surface) structural features and defects that are involved in the oxygen dissociation process.

The primary goal for Project 2 is to develop the experimental protocols to determine the crystallographic nature of the interfaces and triple-phase boundaries in SOFCs, as well as to establish a basic understanding of the factors that determine their populations and evolution.

Objectives:

Project 1: In-Situ Spectroscopy on SOFC Cathode Materials

Project 1 has the following objectives:

- Develop a better understanding of the oxygen species present on cathode materials and compare these results with predictions from computational chemistry calculations. This will require implementing an *in-situ* Raman experiment to get the vibrational spectra of superoxide and peroxide oxygen species on cathode materials like LSM. The experimental vibrational spectra will be compared to calculated spectra.
- Develop a quantitative picture of how much of each form of oxygen exists on a cathode surface. This quantification will be conducted through temperature-programmed desorption/reduction/oxidation (TPD/TPR/TPO) studies of oxygen interactions with common cathode materials like LSM. The role of different processing methods (heating cycles, exposure to various gases) on the amount and types of oxygen species will be investigated by using combinations of TPR and TPD. A quantitative estimate of the binding energy for each of the oxygen species will be conducted via desorption measurements (TPD).
- Synthesize novel high-surface area cathode materials for Raman and TPD/TPO/TPR experiments. Developing methodologies for incorporating these materials into functioning SOFC button cells for testing will also be investigated.
- Investigate the (surface) structural features associated with oxygen adsorption on epitaxially grown thin films of cathode materials. These thin films will serve as model surfaces with well-defined crystallographic faces which will connect surface experiments with computational chemistry calculations. In addition to surface defects, any segregation of lanthanum (La), strontium (Sr), or other species will be investigated and the amounts of these species on the surface will be quantified.

Project 2: Studies on the Evolution of Crystallographic Nature of Cathode Microstructural Features in SOFC in Operating Conditions

Project 2 has the following objectives:

- Develop a basic understanding of the interfacial (grain boundary, solid-phase boundary, and surface) populations and energies of YSZ and LSM, as a function of thermal and electrochemical loads.
- Obtain a quantitative understanding of the crystallographic nature of the cathode microstructure, including the grain boundary structure, surface orientations, and two-phase and triple phase boundary structure.
- Relate the processing history and performance to the crystallographic nature of the microstructural features of the SOFC cathode.
- Develop processing methods that lead to improved performance owing to an increase in the population of specific crystallographic microstructural features in the cathode microstructure.

11: FWP-49071

Project Number FWP-49071	Project Title Solid-Oxide Fuel Cell Research and Development—SYNCHROTRON			
Contacts DOE/NETL Project Mgr.	Name Briggs M. White	Organization Power Systems Division	Email briggs.white@netl.doe.gov	
Principal Investigator	Paul Fuoss	Argonne National Laboratory-IL (ANL)	fuoss@anl.gov	
Partners	Paul Salvador, Carnegie-Mellon University Bilge Yildiz, Massachusetts Institute of Technology Hoydoo You, Argonne National Laboratory Jeffrey Eastman, Argonne National Laboratory Dillon Gong, Argonne National Laboratory Kee-Chul Chang, Argonne National Laboratory Brian Ingram, Argonne National Laboratory Timothy Fister, Argonne National Laboratory Walter Harrison, Stanford University			
Stage of Development	X__ Basic R&D	__ Applied R&D	__ Proof of Concept	__ Demonstration

Technical Background:

X-ray synchrotron radiation techniques offer exceptional capabilities to monitor, characterize, and quantify the structural and chemical state of surfaces, buried interfaces, and thin surface layers. These techniques are unique in their ability to penetrate a gas processing environment and probe in situ the state of a sample held at high temperature and under electrochemical polarization.

The project's studies of perovskite solid-oxide fuel cell (SOFC) materials utilize the capabilities developed at ANL to provide two complementary approaches: one allowing the in-situ x-ray study of thin films under controlled atmosphere and temperature, and the other under controlled temperature and electrochemical potential. In-situ x-ray scattering measurements are performed using the extreme environment processing (EEP) system that is capable of performing surface-sensitive x-ray scattering and spectroscopy measurements in gas environments from atmospheric pressure to 10-8 Torr, and from room temperature to 1,000 °C. This system is used to simultaneously characterize surface and bulk structures using x-ray diffraction and to determine surface segregation profiles as a function of temperature and oxygen partial pressure.

Similarly, an apparatus operable in full-cell or half-cell modes was developed to study the physical and chemical phenomena responsible for the non-stationary electrochemical behavior of perovskite SOFC electrodes. This apparatus is used to perform depth-sensitive x-ray studies of the effects of electrochemical polarization and temperature on the chemical composition, oxidation state, and structural phases of thin-film perovskite SOFC cathodes during cell operation in air. The team uses reflection x-ray absorption near-edge structure (refXANES) for identifying the chemical composition and oxidation-states, and reflection extended x-ray absorption fine structure (reflEXAFS) for identifying the bond lengths and local coordination environment of the A- and B-site cations. Depth-sensitive (i.e., grazing incidence) powder diffraction is used to identify possible phase transformations during the electrode polarization and heating.

The experimental results from both systems will be integrated and compared in order to understand and differentiate the effects of oxygen partial pressure, electrochemical potential, and current on perovskite oxygen electrodes. These results will be used to relate and validate ex-situ measurements as a probe of structural changes in SOFC materials.

Relationship to Program:

This project supports vital cathode performance advances within the Solid State Energy Conversion Alliance (SECA) Core Technology Program.

The performance of fuel cells is strongly influenced by the nanoscale structure and chemistry of electrode materials under operating conditions. This work provides accurate measurement of these important properties under in-situ conditions and tests the validity of conclusions based the ex-situ measurements. The in-situ results obtained in this project will have significant impact on accelerated development of new and improved cathode materials for future fuel cell systems.

Primary Project Goal:

The goal of this project is to determine the atomic and nanoscale structure of SOFC cathode materials under conditions typical for fuel cell operation (high temperature and near atmospheric pressure operation), and to use those results to validate conventional ex-situ (e.g., those performed in ultra-high vacuum) determinations of structure and provide molecular-level models that can stimulate rational design and development of high-performance cathode materials.

Objectives:

This project has the following objectives:

- Determine the structure of La_1-xSr_xMnO_3 (LSM) thin films as a function of oxygen partial pressure and temperature. Examine the role of strain state and x-ray background introduced by substrate choice, and use this information to develop optimized sample geometries
- Study the chemical and atomic structure of LSM and La_1-xSr_xCoO_3 (LSC) thin-film cathodes on yttria-stabilized zirconia (YSZ) electrolytes in an SOFC half-cell configuration as functions of operating temperature and electrochemical potential
- Correlate measurements from the above two objectives with ex-situ measurements from the literature.
- Integrate the electrochemical measurements into the controlled environment system.
- Study the operation of the cathode side of a fuel cell and correlate the structural and chemical state with those determined by ex-situ measurements from the literature and supplemental measurements performed at ANL, Carnegie Mellon University (CMU) and the Massachusetts Institute of Technology (MIT).

12: MSD-NETL-01

Project Number MSD-NETL-01	Project Title Development of Inexpensive Metal Alloy Electrodes for Cost-Competitive Solid-Oxide Fuel Cells			
Contacts DOE/NETL Project Mgr.	Name Briggs M. White	Organization Power Systems Division	Email briggs.white@netl.doe.gov	
Principal Investigator	Steven J. Visco	Lawrence Berkeley National Laboratory (LBNL)	sjvisco@lbl.gov	
Partners	None			
Stage of Development	_X_ Basic R&D	__ Applied R&D	__ Proof of Concept	__ Demonstration

Technical Background:

The research team at the Lawrence Berkeley National Laboratory (LBNL) has tremendous experience and resources in solid-state chemistry, electrochemical systems, ceramic and metal processing, nanotechnology, and analytical and microstructural characterization of materials. Accordingly, the team is well suited to carry out basic research in the field of solid-oxide fuel cells (SOFCs) and has been very active in transitioning technology to the private sector.

Relationship to Program:

This project supports vital materials and manufacturing advances within the Solid State Energy Conversion Alliance (SECA) Core Technology Program.

The LBNL team is working with two American companies interested in supplying U.S. developers with high quality electrodes for the SOFC stacks; neither company had experience in this field prior to the efforts of LBNL to assist them. LBNL has also transferred its infiltration technology to industrial developers and other national laboratories in an effort to accelerate SOFC commercialization.

Primary Project Goal:

The primary goal for the LBNL SECA effort is to develop technologies that improve the performance of SOFC components in a reliable and predictable fashion, aiding U.S. fuel cell developers in enhancing their competitiveness in the energy field. Specifically, the LBNL team has focused on unique infiltration technology to create functional nanostructures on the surface of fuel cell electrodes to enhance low-temperature performance. Additionally, LBNL has developed surface coatings to improve oxidation resistance and reduce chromium volatilization from metallic components, and has developed a "standard stack" design to allow comparative testing of SOFC components at national laboratories, universities, and industry.

Objectives:

The key objectives of the LBNL effort are:

- Infiltration of pervovskites and other appropriate catalysts into composite cathodes
- Determination of baseline performance and long-term stability of infiltration and non-infiltrated air cathodes
- Infiltration of ceria and other appropriate materials into nickel-yttria-stabilized zirconia (Ni-YSZ) to improve sulfur tolerance
- Design and fabrication of a two-cell stack for national laboratories and industrial teams as a standard platform for testing electrodes and seals

13: DE-FC26-02NT41572

Project Number DE-FC26-02NT41572	Project Title Functionally Graded Cathodes for Solid-Oxide Fuel Cells			
Contacts DOE/NETL Project Mgr.	Name Briggs M. White	Organization Power Systems Division	Email Briggs.white@netl.doe.gov	
Principal Investigator	Meilin Liu	Georgia Institute of Technology	Meilin.liu@gatech.edu	
Partners	Delphi Georgia Institute of Technology			
Stage of Development	_X_ Basic R&D	__ Applied R&D	__ Proof of Concept	__ Demonstration

Technical Background:

The cathode is an important area of solid-oxide fuel cell (SOFC) development because most of the cell power losses arise in the cathode, more so at lower operating temperatures. Our novel cathode consists of a porous backbone of high ionic and electronic conductivity (such as lanthanum strontium cobalt ferrite [LSCF]) infiltrated with a thin coating of catalysts having high stability and catalytic activity toward O_2 reduction. The novelty of our cathodes is in the selection and the detailed microstructure of materials that create a better-performing cathode. The hypothesis is that the performance of such a cathode can be enhanced by either improving the transport properties of the backbone or the catalytic activity of the catalyst, or both. This approach integrates materials of different properties and makes the best use of them. Since LSCF has excellent ionic electronic conductivity, the performance of stand-alone LSCF cathodes is likely limited by the surface catalytic activity. Thus, infiltrating a porous LSCF backbone with a catalytically active coating material (such as lanthanum strontium manganite [LSM], samarium strontium cobalt [SSC], etc.) to enhance the catalysis of oxygen reduction at the gas-solid interface should further enhance the performance of the cathodes.

Relationship to Program:

This project supports vital materials and manufacturing advances within the Solid State Energy Conversion Alliance (SECA) Core Technology Program. The project focuses on several aspects of enhancing cathode performance, including:

- Reducing the area specific resistance (ASR) of the cathode
- Improving the stability and operational life of cathodes and SOFCs
- Reducing the sensitivity to contaminants poisoning with a poisoning-tolerant coating
- Developing a unique process to modify electrode surfaces for better performance
- Offering new design of cathode architecture

In-situ techniques will permit an additional processing step (solution infiltration of catalysts into the porous cathode) without adding an additional firing.

Primary Project Goal:

The primary goal of the project is to determine if the stability and/or catalytic properties (or the performance) of porous LSCF cathodes can be further enhanced by infiltration of other catalytically active materials (such as LSM, SSC, etc.).

Objectives:

The project has the following objectives:

- To develop a strategy for reliable testing of surface catalytic properties of a thin-film cathode material without the limitation of sheet resistance
- To determine the effect of surface modification of porous LSCF (by infiltration of another catalyst) on the area-specific polarization resistance

- To perfect processing procedures for fabrication of test cells with LSCF electrodes of controlled density/porosity, thickness, morphology, and performance
- To determine the optimal thickness of LSCF and coatings by sputtering
- To evaluate stability over time (~100 hours testing)

14: DE-FC26-05NT42516

Project Number DE-FC26-05NT42516	Project Title Development of Sulfur- and Carbon-Tolerant Reforming Alloy Catalysts Aided by Fundamental Atomistic Insight			
Contacts DOE/NETL Project Mgr.	Name Ayyakkannu Manivannan	Organization Power Systems Division	Email ayyakkannu.manivannan@netl.doe.gov	
Principal Investigator	Suljo Linic	University of Michigan	linic@umich.edu	
Partners				
Stage of Development	__ Basic R&D	X Applied R&D	__ Proof of Concept	__ Demonstration

Technical Background:

Current hydrocarbon reforming catalysts (usually nickel [Ni] supported on oxides) suffer from rapid carbon and sulfur poisoning. The rapid poisoning of the reforming catalysts has been one of important obstacles for the development of viable solid-oxide fuel cell (SOFC) technology that relies on the direct, on-cell utilization of hydrocarbon fuels.

Even though there is a tremendous incentive to develop more efficient reforming catalysts and electro-catalysts, these materials are currently formulated using inefficient trial and error experimental approaches. We have utilized a hybrid experimental/theoretical approach, combining quantum density functional theory (DFT) calculations and various state-of-the-art experimental tools, to formulate carbon tolerant reforming catalysts. We have employed DFT calculations to develop molecular insights into elementary chemical transformations that lead to carbon poisoning of Ni catalysts. Based on the obtained molecular insights, we have identified, using DFT quantum calculation, Sn/Ni alloys as a potential carbon tolerant reforming catalyst. The tin (Sn)/Ni alloy catalysts were synthesized and tested in steam reforming of methane, propane, and isooctane. We demonstrated that the alloy catalyst is carbon-tolerant under nearly stoichiometric steam-to-carbon ratios. Under these conditions, monometallic Ni is rapidly poisoned by carbon deposits. We have also preformed preliminary testing of the alloy catalysts as anodes for on-cell utilization of hydrocarbon fuels over SOFCs. The initial results are promising.

The research approach is distinguished by a few unique characteristics: A knowledge-based, bottom-up approach, compared to the traditional trial and error approach, allows for a more efficient and systematic discovery of improved catalysts; and the focus is on exploring alloy materials which have been largely unexplored as potential reforming catalysts.

Relationship to Program:

This project supports vital fuel processing advances within the Solid State Energy Conversion Alliance (SECA) Core Technology Program.

This project will have direct impact in the area of novel carbon-tolerant hydrocarbon reforming catalysts on the viability of SOFC technology, and long-term impact in the area of discovery of novel catalysts and electrocatalysts. The project includes the following benefits:

- Aside from being involved in hydrocarbon conversion into synthesis gas (syngas), robust reforming catalysts could also be integrated as anodes for internal (direct) utilization of hydrocarbons in SOFCs
- The development of an active and stable reforming catalyst would have a far-reaching economical impact that will extend beyond the H_2-production aspect of reforming
- The rational, bottom-up approach to catalyst discovery based on the molecular understanding of the elementary chemical transformations that govern the catalyst performance will allow for a more efficient formulation and optimization of novel catalysts and electro-catalysts. The team believes that this approach is particularly important for exploring various bimetallic or even multi-element alloy materials

Primary Project Goal:

The project's primary goal is to utilize state-of-the-art experimental and theoretical techniques, combining quantum DFT calculations and various experimental tools, to develop molecular mechanisms that govern the process of carbon poisoning of reforming catalysts. These molecular insights are further used to formulate carbon-tolerant catalysts and electro-catalysts for hydrocarbon reforming, and as anodes for the direct utilization of hydrocarbon fuels on SOFCs.

Objectives:

The project has the following objectives:

- Identify chemical mechanisms that govern the process of carbon poisoning of Ni
- Utilize the molecular insights to identify Ni-containing alloy electrocatalysts that offer superior carbon-tolerance compared to monometallic Ni electrocatalysts
- Synthesize the identified novel alloy catalysts
- Test the alloy catalysts as anodes for SOFCs and as catalysts for reforming of hydrocarbons

15: FWP-40552

Project Number FWP-40552	Project Title Low-Cost Modular SOFC Development—Modeling			
Contacts DOE/NETL Project Mgr.	Name Ayyakkannu Manivannan	Organization Power Systems Division	Email ayyakkannu.manivannan@netl.doe.gov	
Principal Investigator	Moe A. Khaleel	Pacific Northwest National Laboratory (PNNL)	moe.khaleel@pnl.gov	
Partners	SECA Industry Teams (Delphi, Fuel Cell Energy, etc.) Oak Ridge National Laboratory SECA core team universities (Georgia Tech, University of Cincinnati, University of West Virginia, etc.)			
Stage of Development	__ Basic R&D	X Applied R&D	__ Proof of Concept	__ Demonstration

Technical Background:

The solid-oxide fuel cell (SOFC) is a complex system involving multiple physical phenomena, such as fluid flow, electrochemistry, electric fields, thermal fields, and mechanical deformation, that are inherently coupled with each other. The challenge to develop a system that creates high electrical power while remaining chemically and structurally stable during operations will only be achieved through the combined efforts of material development, experimental testing, and numerical modeling.

Modeling is an essential component to speeding the development of successful stack designs. In order to efficiently develop and optimize planar SOFC stacks to meet technical performance targets, it is desirable to experiment numerically with the effects of geometry, material properties, operational parameters, and thermal-mechanical loading. The computations with representative baseline designs, validated by experimental data, have been used to develop a better understanding of the stack behavior while avoiding costly and time-consuming experiments.

In order to model the coupled physics associated with an SOFC stack, Pacific Northwest National Laboratory (PNNL) has developed integrated models to study SOFC single cells and multiple cell stacks. The fundamental building blocks of the modeling and simulation tools are electrochemical models, heat and mass transfer simulations, computational mechanics, and experimental data. Electrochemical relationships are not generally part of commercial software packages, so customized user subroutines were created to simulate the electrochemical reactions occurring in the cell based on PNNL's semi-empirical electrochemistry model, which was generated from actual cell performance data. The electrochemical routines were implemented in both computational fluid dynamics (CFD) and finite element analysis (FEA) software tools and validated against experimental data. This work was first implemented in a commercial CFD fuel cell product, Expert System (es-sofc) by CD-adapco, to generate and analyze planar SOFC stacks. The models were later used to create the standalone solver "SOFC-MP," which solves the flow, thermal, and electrochemical problems. SOFC-MP was then integrated with the user-friendly graphical user interface (GUI) "Mentat-FC," based on MSC Software's Marc finite element analysis (FEA) program to evaluate the mechanical response. The GUI contains a material database and works directly with SOFC-MP and the MARC solver to quickly build, solve, and analyze planar stacks models. This modeling tool suite combines the versatility of a commercial multi-physics code and a validated electrochemistry calculation routine to predict the gas flow distributions, current distribution, temperature field, and power output for stack-level simulations. One advantage of the newest simulation tool is that it uses reduced order modeling to very quickly evaluate the fuel cell stack performance.

The developed multi-physics modeling tools were used to study a wide range of performance design criteria as part of PNNL's research activities under SECA. The tools have also been distributed for use by SECA industry teams and academic partners. Currently, the tools are being continually advanced and used to address programmatic material development and degradation challenges. The effect of thermal cycling on seal damage and loss of hermeticity (i.e., leakage) was studied, as was the use of the endothermic reaction for on-cell reformation of methane as a thermal management technique. A probabilistic-based component design methodology was developed, which takes into account the randomness in SOFC material properties and stresses arising from different manufacturing and operating conditions. For SOFC materials and stack development, the time-dependent mechanical response of seal and interconnect components was considered to predict the impact on stack performance and component stresses. Interconnect scale-growth was evaluated for both its mechanical durability to resist growth-induced spallation, as well as its influence on the cell electrochemistry. The modeling tools were also used to evaluate issues expected to be problematic for cell scale-up, such as high stresses and loss of contact in the stack. PNNL is also working with ORNL and ASME to develop an SOFC design methodology based on the modeling tools and techniques developed under the program. Modeling activities for two of these subtasks will be addressed in further detail: 1) the impact of glass-ceramic sealants and their inherent time-dependent mechanical response on seal and cell durability, and 2) the increased demands for superior thermal management as stack designers strive to achieve higher power output by using larger cell areas.

1. Creep of Glass-Ceramic Sealants – Materials used to ensure that the fuel and oxidant gas flows in the SOFC remain segregated and hermetic have included rigid sealants, compressive sealants, gaskets, and brazes. Glass-ceramic materials have been found suitable to bond different SOFC components because they are inexpensive and easy to apply, and they have good mechanical performance at high temperatures, chemical compatibility with other fuel cell components, low volatility, high electrical resistance, low mismatch of coefficients of thermal expansion (CTEs) with joined components, and good adherence. One advantage of using glass ceramics as sealant materials is that the properties of these composite materials can be tailored by modifying their constituents' properties and characteristics. Since various manufacturers will use different materials with different CTEs, this advantage is critical for wider application where properties can be tailored for the specific application. The glass-ceramic sealant is formed by bringing the initial glass constituents to high temperature where the viscous liquid wets the surfaces to be joined. With additional heat treatment, the sealant also begins to rapidly crystallize, forming various ceramic phases which give strength and stiffness to the glass-ceramic composite. Depending on the crystallization kinetics, the amount of reinforcement phase can be then be controlled. The remaining volume fraction of residual glass in the glass ceramic was found to be important to the mechanical behavior of the sealant. At cell operating temperatures, the ceramic phases are expected to behave elastically linear with high strength to failure, but the residual glassy phase is expected to exhibit viscoelastic/viscoplastic behaviors. The mechanical response of the composite, and hence stresses in the SOFC stack, will then depend on the composition and morphology of this composite.

Reliable sealing has repeatedly been a top priority for the SECA research program, as seal failure is a major degradation mechanism for the SOFC. Early PNNL modeling activities for glass-ceramic sealants evaluated the material with a continuum damage mechanics model. The results captured seal damage behaviors consistent with experimental stack testing, but seemed to overestimate the developed thermalmechanical stresses. Further experimental characterization was performed on PNNL's glass-ceramic G18, which confirmed that the sealant exhibited time-dependent mechanical behavior attributed to the residual volume of glassy material. This additional compliance is very important for stack stress predictions. Concurrently across SECA, ongoing materials development research studied very different sealant technologies: materials with nearly full crystallization to provide very high strength and stiffness versus materials with no crystallization to provide very low stiffness and "self-healing" capabilities. The stack simulation models are well-suited to evaluate this wide range of material behaviors that characterize the advantages/disadvantages as an SOFC sealant. The highly rigid seal may have suitable strength to avoid fracture, but the high stiffness may not easily accommodate thermal strain mismatch between the ceramic cell and the metallic interconnect. The viscous seal may be able to accommodate the thermal strain mismatch, but the continued deformation of the seal may cause cell displacement that interrupts the electrical connection with the interconnect. Therefore, both experiments and modeling efforts were initiated to characterize the time-dependent deformation of glass-ceramic seal compositions, develop appropriate constitutive models, and evaluate the performance in realistic stack designs.

2. Thermal Management of Large Cells – For large SOFC stacks, thermal management is a critical issue for reliable operation. Stable electrochemical performance of the electrodes, electrical performance of the contact materials, and thermal-mechanical performance of these materials (particularly interconnects and seals) depend in part upon the maximum temperature they experience under long-term operation. The materials will perform more stably at lower temperatures. Additionally, stresses will be present within the stack materials and interfaces due to thermal gradients, temperature differences, and thermal expansion mismatches. Differences in temperature within the stack (and across a cell) are created by cooling the stack with inflowing cathode air and fuel on one hand, and the net heat load resulting from the electrochemical reactions on the other. When the difference between the minimum and maximum cell temperatures (ΔT) is minimized, then the maximum temperature will be minimized as well. The most beneficial condition might be achieved when the maximum temperature and ΔT are minimized using simple and relatively inexpensive means of distributing the net heat load within the stack, and improving heat removal by conduction, convection, and radiation heat transfer.

Relationship to Program:

This project supports vital modeling and simulation advances within the SECA Core Technology Program.

The models developed under this task integrate the multiple, strongly coupled phenomena in SOFCs to provide a single package for SOFC analysis. This reduces the software that must be purchased, reduces modeling time by sharing common data structures, and allows the average analyst to evaluate the complete response of the SOFC. In addition to characterization of the basic electrochemical and structural behavior, companion tools for targeted evaluation of seals, coatings, material damage, on-cell reformation, reliability, creep, and other high-priority design challenges are also being developed. The availability of these tools will help spur innovation and accelerate stack design.

Primary Project Goal:

The goals of the specific project tasks under review are:

1. Creep of Glass-Ceramic Sealants – Use numerical modeling and experiments to identify material properties and structures for reliable sealants during stack operations.
2. Thermal Management of Large Cells – Use thermal-mechanical modeling tools to ensure large area cells can sufficiently accommodate higher electrochemical heat loads to prevent cell material damage.

Objectives:

The objectives of the specific project tasks under review are:

1. Creep of Glass-Ceramic Sealants – (a) develop numerical models to study the effects of time-dependent deformations on stack component stresses, (b) develop constitutive material models to simulate the experimentally-determined viscoelastic/plastic behaviors of glass-ceramic sealants, (c) simulate seal performance during stack operations and compare against experimental testing when available, (d) develop structure-property relationships for the composite seal materials, and (e) provide recommendations to sealant developers for desirable target compositions, morphologies, and properties.
2. Thermal Management of Large Cells – (a) use existing modeling tools to understand the heat removal requirements for scaled-up cells, (b) characterize the benefits and drawbacks of different heat removal mechanisms during stack operations, (c) ensure that temperature limits and mechanical reliability targets can be achieved for large cells, and (d) establish guidelines for utilizing different heat removal mechanisms within large cells.

16: ORD-07-220611

Project Number ORD-07-220611	Project Title Fuel Processing & Hydrogen Production			
Contacts DOE/NETL Project Mgr.	Name Abbie Layne	Organization Separation & Fuels Processing Division	Email abbie.layne@netl.doe.gov	
Principal Investigator	David A. Berry	Separation & Fuels Processing Division	david.berry@netl.doe.gov	
Partners				
Stage of Development	X Basic R&D	__ Applied R&D	__ Proof of Concept	__ Demonstration

Technical Background:

In order for solid-state fuel cell systems to demonstrate high efficiencies, they must be coupled with fuel processors with a high degree of thermal integration. They must also be capable of achieving specifications required for the stated application and supply the fuel cell with a clean, hydrogen-rich synthesis gas that is low in hydrocarbon content. Many applications will reflect fuel processing of high energy density fuels, such as gasoline, diesel, jet propellant 8 (JP-8), military logistics fuels, coal-derived fuels, bio-fuels, etc. For these systems, conversion of sulfur-containing feed stocks into a sulfur-free fuel gas that is high in hydrogen and carbon monoxide is necessary for use in the fuel cell. Poisoning of both reforming catalysts and fuel cell anodes via sulfur and carbon deposition are of primary concern. Understanding these mechanisms and developing sulfur- and carbon-tolerant reforming technology is critical to the program, along with identification, development, and demonstration of novel fuel processing approaches.

Relationship to Program:

This project supports vital fuel processing advances within the Solid State Energy Conversion Alliance (SECA) Core Technology Program.

For fuel cells to effectively enter the marketplace, viable fuel processing technologies for conversion of current infrastructure fossil fuels need to be in place. In this sense, fuel processing/reforming is an enabling technology that is required for fuel cell commercialization for a broad number of fuels and market applications. The technology of fuel-reforming chemistry has potentially broad applicability to a number of other chemical processes that proceed through similar reaction mechanisms. The relatively novel and fundamental nature of the work performed in this project can have much wider impact beyond fuel cell systems.

Primary Project Goal:

The primary goal of this project is to identify viable hydrocarbon fuel processing technologies for high temperature SOFCs in the SECA program, through fundamental understanding, evaluation, and demonstration.

Objectives:

The project has the following objectives:
- Apply a fundamental understanding of fuel reforming and deactivation mechanisms into intelligent design of alternative catalyst systems for long-term, stable, hydrogen-rich synthesis gas production
- Identify and evaluate alternative non-catalytic and/or catalyst-assisted processes to overcome deactivation of traditional catalytic fuel reforming of higher hydrocarbon compounds

17: ORD-08-220621A

Project Number ORD-08-220621a	Project Title Coal-Based Fuel Cells—Contaminant Testing			
Contacts DOE/NETL Project Mgr.	Name Dan Maloney	Organization Energy Systems Dynamics Division	Email daniel.maloney@netl.doe.gov	
Principal Investigator	Randy Gemmen	Energy Systems Dynamics Division	randy.gemmen@netl.doe.gov	
Partners	West Virginia University (URI Program) Carnegie Mellon University (URI Program)			
Stage of Development	X Basic R&D	_ Applied R&D	_ Proof of Concept	_ Demonstration

Technical Background:

This project supports DOE's mission to integrate coal gasification and fuel cell technologies for achieving highly efficient and environmentally clean electric power generation. This project will explore the effect of residual trace contaminants on fuel cell operation. Exploring this relationship will allow NETL industry partners to effectively develop low-cost solid-oxide fuel cell (SOFC) technology for coal-based applications. This project focuses on the interaction of the SOFC anode with volatile inorganic species derived from coal during the gasification process. This project is unique in that it will perform testing using coal synthesis gas (syngas) derived directly from a coal gasifier. The trace elements naturally occurring in coal that might be expected in our tests include vanadium, chromium, manganese, cobalt, nickel, zinc, molybdenum, cadmium, lead, mercury, antimony, arsenic, and others.

The exact trace species to which an SOFC may be exposed are dependent on the coal type, coal source, gasifier design, and syngas cleanup train. From past work, the project team knows that the trace materials most likely to interact with the cell anode are antimony, arsenic, and phosphorous. To a lesser degree, mercury, lead, antimony, selenium, cadmium, and higher order hydrocarbons may also be of concern. The trace materials may induce cell performance degradation by blocking gas diffusion paths (e.g., by chemisorption of trace material), by creating a stable but poorly performing secondary surface or bulk phase (e.g., nickel arsenide), or through a secondary deactivation mechanism (e.g., forced absorption of species into the bulk). The key technical challenges for our work include identification of trace species contained in coal syngas to which the SOFC is exposed, assessment of the likely interaction mechanisms between the SOFC anode and the trace species, and quantification of the permissible level of a given species exposure that sustains satisfactory degradation performance (e.g., <0.1% per 1,000 hours).

Relationship to Program:

This project supports DOE's mission to integrate coal gasification and fuel cell technologies for achieving highly efficient and environmentally clean electric power generation. The project provides a range of research support that will offer SOFC developers the following benefits:

- Enhanced understanding of trace material interaction processes with SOFC anodes
- Quantification of cleanup target levels for trace materials in coal syngas delivered to SOFCs
- Capability to perform high-throughput SOFC testing via a portable skid that can access a variety of fuel streams (coal gasifiers, biomass gasifiers, etc.)
- Development of data collection methods for online, real-time quantification of volatile trace species in coal syngas via gas chromatography inductively coupled plasma mass spectrometry (GC-ICP-MS) techniques

Primary Project Goal:

This project's primary goals are to use experimental testing and theoretical analysis to identify processes and mechanisms by which trace coal syngas species interact with the anode of SOFCs, and to predict the effect of trace material exposure levels which will be acceptable to SOFC operation.

Objectives:

This project has several objectives:

- Perform tests using button cells directly on coal syngas at the Power System Development Facility in Wilsonville, AL. This requires the development and subsequent field operation of the SOFC multi-cell array test skid.
- Perform individual trace species studies to examine the effect of exposure of volatile compounds of selenium, lead, mercury and/or carbonyl sulfide on the cell performance and microstructure. Use these more fundamental tests to identify mechanism(s) and rate equation(s) for the contamination process.
- For the above two objectives, perform online gas analysis of the syngas matrix (containing contaminants) with a GC-ICP-MS analytical system. Develop methods for sample capture, sample processing, and data analysis.
- Conduct post-operation microscopy analysis on samples using x-ray diffraction, x-ray photoelectron spectroscopy, and scanning electron microscopy (at NETL), and secondary ion mass spectrometry (at Carnegie Mellon University).

18: DE-FC26-02NT41567

Project Number DE-FC26-02NT41567	Project Title A Low-Cost Soft-Switched DC/DC Converter for Solid-Oxide Fuel Cells			
Contacts DOE/NETL Project Mgr.	Name Charles T. Alsup	Organization Power Systems Division	Email charles.alsup@netl.doe.gov	
Principal Investigator	Jason Lai	Virginia Polytechnic Institute	laijs@vt.edu	
Partners	None			
Stage of Development	_ Basic R&D	X Applied R&D	_ Proof of Concept	_ Demonstration

Technical Background:

The power-conditioning system of a typical fuel cell requires a DC-to-DC converter and a DC-to-AC inverter to convert the unregulated low-voltage DC voltage from the fuel cell to regulated AC output for utility grid tie or household applications. The DC-to-DC converter is the first step of the power-conversion process. The converter takes the unregulated low-voltage DC output from the fuel cell and converts it to a high-voltage DC source suitable for downstream power conversions. For utility grid connections or AC load applications, a DC-to-AC inverter is used to convert the high-voltage DC to AC output. Currently, the two major limiting factors of fuel cell power-conditioning systems are high costs and low efficiency. The crux of this research is a reduction in cost and an increase in efficiency for these conditioning systems.

The peak efficiency of the subject V6 DC-to-DC converter was reported at 96.5%, with either 25 V or 50 V fuel-cell voltage. Recently, the 50 V level peak efficiency at the half load was further improved to 97.3% by reducing the power metal oxide semiconductor field effect transistor (MOSFET) turn-off loss with a smaller gate-drive resistance. The efficiency at the 5-kW rated load is about 96.5%.

For the DC-to-AC inverter, the proposed soft-switching inverter shows 99% efficiency for the switching stage. After adding an inductor-capacitor-inductor (L-C-L) filter, the efficiency remains 98%. The problem is that the originally used solid-state relay consumes another 1% loss, and in addition the relay itself requires separate heat sink and cooling. Recently, the team developed a hybrid contactor that combines the solid-state relay and a mechanical contactor to eliminate the loss and to maintain high efficiency operation.

The utility grid interface adopts an LCL filter that allows universal applications. In other words, it can operate in both standalone and grid-tie modes. In order to control such an LCL filter-based system, an admittance compensation technique was proposed to allow simple control design with well-defined control loop stability. A provisional patent has been filed through the Virginia Tech Intellectual Property office.

Relationship to Program:

This project supports vital power electronics advances within the Solid State Energy Conversion Alliance (SECA) Core Technology Program.

This research seeks to remove the two major limiting factors of fuel cell power-conditioning systems: high costs and low efficiency. High efficiency power conversion is essential to allow the converter and fuel cell to run at lower temperatures with higher reliability and lower fuel consumption. The project will provide the following improvements in power conditioning systems:

- Reduction of power loss via high-frequency soft-switching techniques
- Reduction of costs via decreased use of passive components such as transformers, inductor, capacitor, copper bar, and heat sinks
- Increased utilization of fuel cell capacity via a technique that reduces the fuel cell current ripple
- Development of a universal power circuit that allows the power conditioning system to operate in stand-alone mode for household appliances and utility grid-tie applications

- Development of a wide range reactive power flow control that allows the inverter to send real and reactive power from 0 to 1.0 full scale power factor, a much higher range than that offered by most existing conditioning circuits in the market

Primary Project Goal:

The primary project goal is to achieve high-efficiency, low-cost power conversion for the solid-oxide fuel cell (SOFC) power-conditioning system, including DC-to-DC and DC-to-AC stages.

Objectives:

The objectives of the project are to:
- Develop a low-cost DC-to-DC converter for low-to-high-voltage power conversion as the standard interface between the SOFC source and the load-side DC-to-AC inverter
- Develop a low-cost 5-kW DC-to-AC inverter with a minimum energy efficiency of 99%, operating with >400 VDC input

APPENDIX F: LIST OF ACRONYMS AND ABBREVIATIONS

AC	alternating current
ANL	Argonne National Laboratory
ASME	American Society of Mechanical Engineers
ASR	area specific resistance
BRTD	Board on Research and Technology Development
CARB	California Air Resources Board
CCC	Copyright Clearance Center
CH_4	methane
CIL	composite interlayer
CMU	Carnegie Mellon University
CO	carbon monoxide
CO_2	carbon dioxide
COE	cost of electricity
CFD	computational fluid dynamics
CPOx	catalytic partial oxidation
Cr	chromium
CRTD	Center for Research and Technology Development
CTE	coefficient of thermal expansion
DC	direct current
DFT	density functional theory
DOE	U.S. Department of Energy
DSC	differential scanning calorimetry
EDS	energy dispersive spectrometry
EEP	extreme environment processing
FCE	FuelCell Energy Inc.
Fe	iron
FEA	finite element analysis
GC-ICP-MS	gas chromatography inductively coupled plasma mass spectrometry
GUI	graphical user interface
H_2	hydrogen
HHV	higher heating value
HPD	high power density
IGFC	integrated coal gasification fuel cell
JP-8	jet propellant 8
La	lanthanum
LBNL	Lawrence Berkeley National Laboratory
L-C-L	inductor-capacitor-inductor

LHV	lower heating value
LSCF	lanthanum strontium cobalt ferrite
LSM	lanthanum strontium manganite
MIT	Massachusetts Institute of Technology
MOSFET	metal oxide semiconductor field effect transistor
MW	megawatt
MWe	megawatt electrical
Nb	niobium
NETL	National Energy Technology Laboratory
Ni	nickel
OCC	Office of Clean Coal
OMB	Office of Management and Budget
ORD	Office of Research and Development
ORNL	Oak Ridge National Laboratory
OSAP	Office of Systems Analysis and Planning
PI	principal investigator
PNNL	Pacific Northwest National Laboratory
ppmv	parts per million by volume
PSA	particle size analysis
reflEXAFS	reflection extended x-ray absorption fine structure
reflXANES	reflection x-ray absorption near-edge structure
SECA	Solid State Energy Conversion Alliance
SEM	scanning electron microscopy
Sn	tin
Sr	strontium
Sr-Ca-Y-B-Si-O	strontium-calcium-yttrium-boron-silicon-oxygen
SSC	samarium strontium cobalt
TEM	transmission electron microscopy
TGA	thermogravimetric analysis
TMS	Technology & Management Services, Inc.
TPD	temperature-programmed desorption
TPO	temperature-programmed oxidation
TPR	temperature-programmed reduction
V	volt
VPS	Versa Power Systems
XPS	x-ray photoelectron spectrometry
XRD	x-ray diffraction
YSZ	yttria-stabilized zirconia