OVERVIEW REPORT

DOE/NETL Clean Coal Research Program
Solid Oxide Fuel Cells Program
FY2014 Peer Review Meeting

Pittsburgh, Pennsylvania
April 16-18, 2014

ASM INTERNATIONAL

OVERVIEW REPORT
CLEAN COAL RESEARCH PROGRAM
SOLID OXIDE FUEL CELLS PROGRAM
FY2014 PEER REVIEW MEETING

Pittsburgh, Pennsylvania
April 16–18, 2014

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Work Performed for U.S Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory Under
Prime Contract DE-FE0004002 (Subtask 300.02.08)

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The work performed on this task/subtask was completed under Leonardo Technologies, Inc. (LTI), Prime Contract DE-FE0004002 (Subtask 300.02.08) for DOE-NETL.

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INTRODUCTION AND BACKGROUND

Solid Oxide Fuel Cells Program Mission and Goals

The National Energy Technology Laboratory (NETL) work on solid oxide fuel cells (SOFC) is part of the Clean Coal Research Program, Carbon Capture and Storage (CCS) and Power Systems research and development effort. The SOFC is an Advanced Energy Systems technology with the potential to supply the technology base needed for the clean, efficient generation of electric power from domestic coal and natural gas. The SOFC is a transformational technology that is expected to be available for demonstration initially with natural gas fuel in the 2015–2030 time frame, including demonstrations in distributed generation applications, and in the 2030–2035 period in integrated gasification fuel cell (IGFC) power plants fueled with coal-derived synthesis gas (syngas).

The national development of an electric power generating system technology based on the SOFC is being pursued because such a system has the following four main benefits:

1. **Generates Electric Power from Coal-Derived Fuel Gas** — the SOFC can operate directly on hydrogen and carbon monoxide, the two main constituents of syngas obtained from the gasification of coal.
2. **Generates Power Efficiently** — the SOFC converts the chemical energy in fuel to electric energy with high conversion efficiency, potentially higher than that of any simple-cycle heat engine.
3. **Provides Excellent Basis for Combined-Cycle System Design** — because the SOFC is a high-temperature technology, an SOFC generator will produce a high-temperature exhaust, and it can be an excellent topping cycle in a high-efficiency combined-cycle system configuration.
4. **Enables Carbon Dioxide (CO_2) Capture** — the SOFC generator module can be configured, by design, to restrict essentially all CO_2 produced to the anode exhaust stream. Water vapor is the only other major constituent in this stream, which will facilitate the separation of the water and CO_2 by relatively simple moisture condensation.

Three industry teams are currently working to develop two power system types—one designed to use SOFC modules that operate at near atmospheric pressure and a second system type that implements pressurized modules:

Atmospheric Pressure Systems — Using anode-supported planar cells, the emphasis in this development is on the design and scale-up of atmospheric–pressure modules that are suitable for integration in distributed generation as well as in utility-scale power systems. Project activities include fabrication, testing, post-test cell analysis, integration of cells in cell stacks, and the development and validation testing of progressively larger stacks.

Pressurized Systems — The SOFC operates with higher power densities when the cell module is pressurized. With cells arranged in a segmented, in-series configuration in the module design, studies indicate that IGFC power systems with the elevated-pressure feature will be capable of operation with electric generating efficiencies at or above 60 percent (higher-heating value [HHV]). Current project activities include examining SOFC material set behavior at elevated pressure; evaluating the effects of pressure on cell performance, reliability, and cell voltage degradation; and identifying and resolving power system design and operational issues associated with pressurizing the SOFC stack.

In parallel with the work of these industry teams, research efforts by other program participants are focused on SOFC anode, electrolyte, and cathode improvements:

Anode-Electrolyte-Cathode Development — This work, performed by universities, national laboratories, small businesses, and other R&D organizations, involves projects that will improve cell power density, reduce degradation, and lead to more robust and reliable systems. Examples of topics of interest in these projects are materials for effective gas seals and cell interconnects, effects of coal contaminants on SOFC materials, fuel processing issues, and balance-of-plant components. Data and results from this work are viewed as important to the successful commercialization of SOFC technologies; they are available to all industry teams, maximizing R&D program usefulness, and striving to avoid R&D duplication.

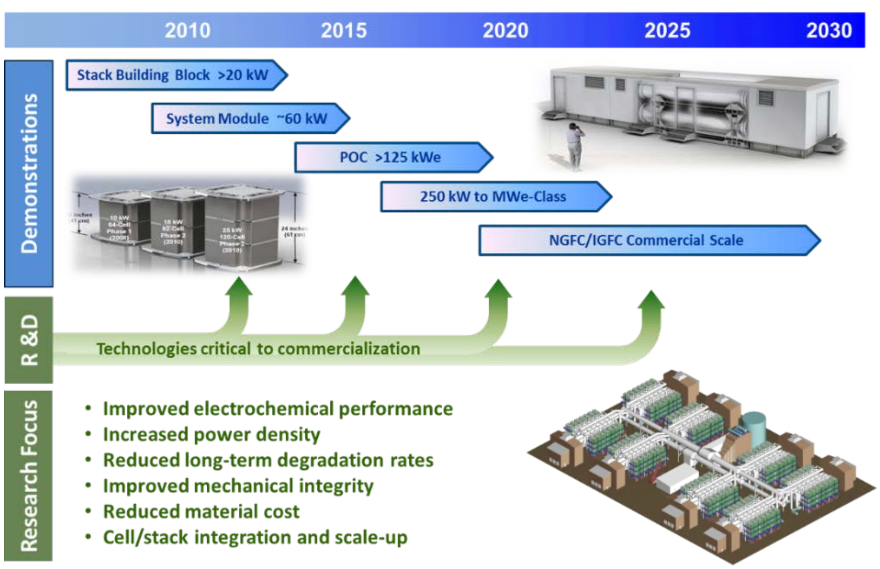
Technical Issues — Two of the primary hurdles facing the commercialization of SOFC power systems are performance degradation rate and cost. The program's specific goals are:

- Degradation: <0.2% per 1,000 hours
- SOFC Stack Cost: $225 (2011 dollars) / kWe projected at high-volume production

The SOFC program maintains a diversified portfolio of projects to address these challenges and ensure a high probability of achieving the desired cost and performance targets.

Figure 1 presents a timeline depiction that illustrates the expected integration of industry team and R&D efforts and activities, and it also projects the intended timing of key program developments. Power system concepts for central-station application have been largely developed by the three industry teams, and the teams are presently working on the design and demonstration of SOFC cell stacks and modules that will be building blocks in their power systems for commercial-market deployment. In current work, atmospheric-pressure module operation at 60 kW has been achieved by one team for over 1,600 operating hours. Another team using a pressurized module design recorded a power output of nearly 19 kW; operated the module, thermally self-sustaining, for 3,000 hours; and experienced a voltage degradation rate of 1.1%/1,000 hours.

FIGURE 1. SOFC PROGRAM DEVELOPMENT TIMELINE



The operation of a thermally self-sustaining system is targeted to occur by 2015, and is to be followed in the 2016–2017 period by a 100 kWe-class demonstration. A program goal, which could be met by the planned completion of the 100 kWe demonstration, is to have a building-block SOFC successfully tested in 2016–2017 using a module design that could then be employed in natural gas-fueled distributed generation demonstrations.

Fuel for use in the early module and MW-class system work could be simulated coal syngas or natural gas. It is envisioned that MW-class demonstration systems, fueled with natural gas, could transition easily to the natural gas distributed generation marketplace. This should happen before the advent of larger, more complex, syngas-fueled power systems, and manufacturing, installation, operation, and maintenance experience gained in the early applications should benefit work continuing in parallel on IGFC system development. Further, natural gas-fueled power systems and the larger IGFC systems could use very similar SOFC module designs. Thus, there is good and potentially beneficial SOFC synergy between the distributed generation and IGFC development efforts.

The demonstration of building-block modules for MWe-class power systems is currently targeted for circa 2020, with the intent to qualify module designs for demonstration in post-2020 integrated gasification settings, prior to full-scale IGFC implementation.

Office of Management and Budget Requirements

In compliance with requirements from the Office of Management and Budget, 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 fiscal year (FY) 2014 Solid Oxide Fuel Cells Peer Review Meeting with independent technical experts to assess ongoing research projects and, where applicable, to make recommendations for individual project improvement.

In cooperation with Leonardo Technologies, Inc., ASM International convened a panel of five leading academic and industry experts on April 16–18, to conduct a three-day Peer Review of selected Solid Oxide Fuel Cells Program research projects supported by NETL.

Overview of Office of Fossil Energy Solid Oxide Fuel Cells Program Research Funding

The total funding of the seven projects reviewed, over the duration of the projects, is $79,858,289. The funding and duration of the seven projects that were the subject of this Peer Review are provided in Table 1 below.

TABLE 1. SOLID OXIDE FUEL CELLS PROGRAM PROJECTS REVIEWED

Reference Number	Project No.	Title	Lead Organization	Principal Investigator	Total Funding		Project Duration	
					DOE	Cost Share	From	To
1	N/A	National Energy Technology Laboratory - Office of Program Performance & Benefits (NETL OPPB)	National Energy Technology Laboratory – Office of Program Performance & Benefits	N/A	N/A	N/A	N/A	N/A
1	OPPB/BD-1	Assessment of Market Potential for Fuel Cells in Distributed Generation Applications	National Energy Technology Laboratory - Office of Program Performance & Benefits (NETL OPPB)	Katrina Krulla	$208,749	$0	02/29/2012	08/30/2013
2	FE0009675	Fundamental Understanding of Oxygen Reduction and Reaction Behavior and Developing High Performance and Stable Cathodes	West Virginia University Research Corporation	Xingbo Liu	$499,953	$134,886	10/01/2012	09/30/2015
3	FWP-2012.03.04 Tasks 1 and 2	NETL-RUA Fuel Cells Initiative: Task 1, Cell and Stack Degradation; Task 2, Cathode Materials and Microstructural Engineering	National Energy Technology Laboratory - Office of Research & Development (NETL ORD)	Kirk Gerdes	$4,000,000	$0	10/01/2012	09/30/2014
4	FWP-40552	SECA Core Technology Program	Pacific Northwest National Laboratory (PNNL)	Jeff Stevenson	$55,889,667	$0	10/01/1999	09/30/2014
5	FE0011769	Solid Oxide Fuel Cell Power System Development	Delphi Automotive Systems, LLC	Rick Kerr	$5,100,027	$1,275,007	10/01/2013	03/31/2015
6	FE0012077	SECA Coal-Based Systems	LG Fuel Cell Systems, Inc.	Richard Goettler	$5,100,000	$1,275,000	10/01/2013	03/31/2015
7	FE0011691	SOFC Systems with Improved Reliability and Endurance	FuelCell Energy, Inc. (FCE)	Hossein Ghezel-Ayagh	$5,100,000	$1,275,000	10/01/2013	03/31/2015
				TOTALS	**$75,898,396**	**$3,959,893**	**--**	**--**

OVERVIEW OF THE PEER REVIEW PROCESS

The U.S. Department of Energy (DOE), the Office of Fossil Energy, and the National Energy Technology Laboratory (NETL) are fully committed to improving the quality and results of their research projects. To support this goal, in fiscal year (FY) 2014, ASM International was invited to provide an independent, unbiased, and timely peer review of selected projects within the DOE Office of Fossil Energy's Solid Oxide Fuel Cells Program. The peer review of selected projects within the Solid Oxide Fuel Cells Program was designed to comply with requirements from the Office of Management and Budget.

On April 16–18, ASM International convened a panel of five leading academic and industry experts to conduct a three-day peer review of seven research projects supported by the NETL Solid Oxide Fuel Cells Program. Throughout the peer review meeting, these recognized technical experts provided recommendations on how to improve the management, performance, and overall results of each individual research project.

In consultation with NETL, who chose the six projects for review, ASM International selected an independent Peer Review Panel, facilitated the peer review meeting, and prepared this report to summarize the results.

ASM International performed this project review work as a subcontractor to prime NETL contractor Leonardo Technologies, Inc.

Pre-Meeting Preparation

Several weeks before the peer review, each project team submitted a project technical summary and a draft final PowerPoint slide deck they would present at the peer review meeting. Additionally, the appropriate federal project manager provided the project management plan and other relevant materials, including project fact sheets, quarterly and annual reports, and published journal articles, that would help the peer review panel evaluate each project. A Key Project Document Index Table helped map the reviewers to the locations within the documents where they could find specific information required to accurately review the project. The panel received all of these materials prior to the Peer Review Meeting via a peer review SharePoint site, which enabled the panel members to come to the meeting fully prepared with the necessary project background information to thoroughly evaluate the projects.

To increase the efficiency of the peer review meeting, a pre-meeting orientation teleconference was held with the review panel and ASM International support staff about one month prior to the meeting to review the peer review process. Additionally, a WebEx meeting with the Technology Manager of the Solid Oxide Fuel Cells Program was held about one month prior to the peer review meeting to provide an overview of the program goals and objectives.

Peer Review Meeting Proceedings

At the meeting, each research team made an uninterrupted 30- to 45-minute PowerPoint presentation that was followed by a 20- to 30-minute question-and-answer session with the panel and a 75-minute panel discussion and evaluation of each project. The time allotted for project presentations, the question-and-answer session, and the panel discussion was dependent on the individual project's complexity, duration, and breadth of scope. To facilitate a full and open discourse of project-related material between the project team and the panel, all sessions were limited to the panel, ASM International personnel, and DOE-NETL personnel and contractor support staff. The closed sessions ensured open discussions between the principal investigators and the panel. Panel members were also instructed to hold the discussions that took place during the question-and-answer session as confidential.

The panel discussed each project to identify and come to consensus on the project strengths, project weaknesses, and recommendations for project improvement. The panel designated all strengths and weaknesses as “major” or “minor” and ranked recommendations from most to least important. The consensus strengths and weaknesses served as the basis for determining the overall project score in accordance with the Rating Definitions and Scoring Plan of the Peer Review Evaluation Criteria Form. Formal strengths, weaknesses, recommendations, and a Project Rating were not recorded for Project 01, Assessment of Market Potential for Fuel Cells in Distributed Generation Applications; instead, the panel provided the project team with comments and suggestions for improving their project during the question-and-answer session.

To facilitate the evaluation process, Leonardo Technologies, Inc. provided the panel with laptop computers that were preloaded with Peer Review Evaluation Criteria Forms for each project, as well as the project materials that the panel members were able to access via SharePoint prior to the peer review meeting.

Peer Review Evaluation Criteria

At the end of the group discussion for each project, the panel came to consensus on an overall project score. The panel scored each project (with the exception of Project 01), as one of the following:

- Excellent (10)
- Highly Successful (8)
- Adequate (5)
- Weak (2)
- Unacceptable (0)

The Rating Definitions that informed scoring decisions are included in Appendix B of this report.

NETL completed a Technology Readiness Assessment of its key technologies in 2012. The technology readiness level (TRL) of projects assessed in 2012 was provided to the panel prior to the peer review meeting. These assessments enabled the panel to appropriately score the review criteria within the bounds of the established scope for each project. Appendix C describes the various levels of technology readiness used in 2012.

SUMMARY OF KEY FINDINGS

This section summarizes the overall key findings of the seven projects evaluated at the FY2014 Solid Oxide Fuel Cells Program Peer Review.

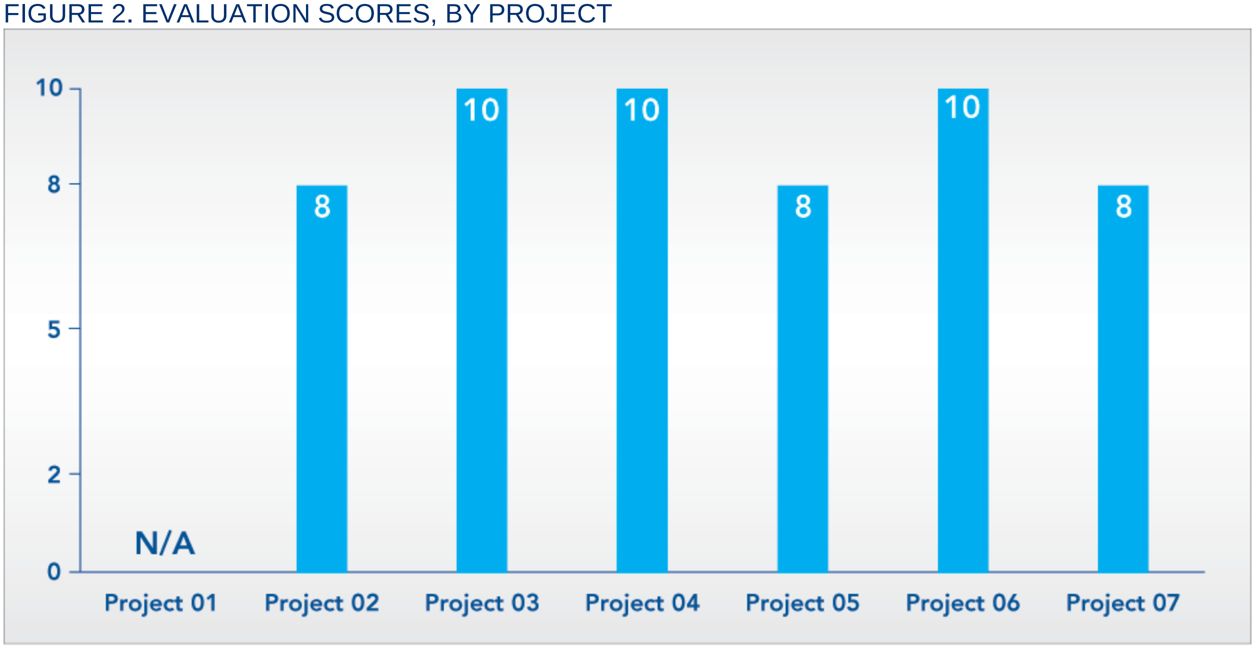
Overview of Project Evaluation Scores

The panel reached consensus on a score for each project:

- Excellent (10)
- Highly Successful (8)
- Adequate (5)
- Weak (2)
- Unacceptable (0)

While it is not the intent of this review to directly compare one project with another, a rating of 5 or higher generally indicates that a specific project was viewed as at least adequate by the panel. The score given to each project is shown in Figure 2.

FIGURE 2. EVALUATION SCORES, BY PROJECT



General Project Strengths

The panel was impressed by the high-quality of all of the Solid Oxide Fuel Cells projects they reviewed from DOE's Clean Coal Research Program. They indicated that the projects presented have ambitious goals and significant potential to advance solid oxide fuel cell technology toward applications in natural gas and coal-based power generation. They also noted that all of the projects reviewed during the peer review are led by knowledgeable and dedicated principal investigators who were open to accepting constructive criticism that could help them improve upon their work. The panel was impressed that the output from the project teams has already had a positive impact on work being conducted by industrial teams and will also serve as a strong foundation for future research and development efforts to advance SOFC-based technologies. Based on the progress made to date by the projects reviewed, the panel was optimistic about the potential for these projects to further progress toward achieving DOE's challenging goals for advancing the reliability, robustness, and durability of cell and stack technology to permit low-cost, low-emission, grid-independent distributed generation using natural gas. Panel members were particularly impressed with the work from the national laboratories and their active engagement with partners in academia and industry. This collaboration brought together a high degree of expertise across team members, which was facilitated through skilled project management by the principal investigators.

Panel members noted that the success of projects was largely attributed to their highly qualified multidisciplinary teams, the development of cost-effective strategies for addressing major SOFC technology hurdles, and the generation of relevant project outputs that can be transferred to industry. All projects were considered "highly successful" or "excellent" and were given ratings of 8 or 10.

General Project Weaknesses

None of the projects in the Solid Oxide Fuel Cells Program received a rating of 5 or lower, indicating that the strengths of each project reviewed outweighed the project's weaknesses. Given the high ratings for all of the projects, there were few common themes across the project weaknesses; weaknesses were unique to each project. Despite the success of the project teams, the panel addressed several concerns about the lack of alternative materials choices, potential design issues, and inadequate testing methods.

General Project Observations and Recommendations

The panel members offered recommendations that were technical in nature and specific to a particular project's technology or approach. Since the panel indicated that all of the projects are on track to meet the stated program goals and are on a viable path to commercialization, the panel's recommendations directly addressed the aforementioned weaknesses and offered suggestions to further improve upon project accomplishments. Panel recommendations included investigating alternative markets to down-hole shale gas applications for SOFC technologies to ensure successful commercialization, collaborating across SOFC project teams to leverage tools and expertise, and utilizing supplementary sets of SOFC test data to enhance modeling and simulation efforts.

PROJECT SYNOPSES

For more information on the Solid Oxide Fuel Cells Program and project portfolio please visit the NETL website: http://www.netl.doe.gov/research/coal/energy-systems/fuel-cells.

01: OPPB/BD-1
ASSESSMENT OF MARKET POTENTIAL FOR FUEL CELLS IN DISTRIBUTED GENERATION APPLICATIONS

Kristin Gerdes, National Energy Technology Laboratory
Dale Keairns and Arun Iyengar, Booz Allen Hamilton

2012 Technology Readiness Level: N/A
DOE Funding: $208,749
Cost Share: $0
Duration: 02/29/2012 – 08/30/2013

Project Evaluation Score
8

This project aims to identify relevant U.S. market segments for early distributed generation (DG) applications, develop a DG SOFC reference plant design to meet the market need, utilize related technology experience to understand the market penetration necessary for a DG SOFC system to be cost competitive, and identify a DG path to utility-scale applications.

02: FE0009675
FUNDAMENTAL UNDERSTANDING OF OXYGEN REDUCTION AND REACTION BEHAVIOR AND DEVELOPING HIGH PERFORMANCE AND STABLE CATHODES

Xingbo Liu, West Virginia University Research Corporation

2012 Technology Readiness Level: N/A
DOE Funding: $499,953
Cost Share: $134,886
Duration: 10/01/2012 – 09/30/2015

Project Evaluation Score
8

The goal of this project is to develop highly active and stable intermediate temperature SOFC cathodes by improving oxygen reduction and reaction (ORR) kinetics and enhancing cation segregation tolerance through introduction of a heterostructured oxygen reactive interface on the bulk cathode surface. The primary objectives are to 1) develop a fundamental understanding of the ORR mechanisms, especially the oxygen exchange behavior between the heterostructured surface and bulk of the cathode through systematic experimental investigations and theoretical modeling; and 2) develop—via a low-cost infiltration method—a cathode with a heterostructured surface that possesses high performance and stability.

03: FWP-2012.03.04 TASKS 1 AND 2
NETL-RUA FUEL CELLS INITIATIVE: TASK 1, CELL AND STACK DEGRADATION; TASK 2, CATHODE MATERIALS AND MICROSTRUCTURAL ENGINEERING

Kirk Gerdes, National Energy Technology Laboratory

2012 Technology Readiness Level: 3
DOE Funding: $4,000,000
Cost Share: $0
Duration: 10/01/2012 – 09/30/2014

Project Evaluation Score
10

The NETL-Regional University Alliance (RUA) Fuel Cell Team performs fundamental SOFC technology evaluation, enhances existing SOFC technology, and develops advanced SOFC concepts in support of the SOFCs program. Research projects are designed to meet critical technology development needs that can be uniquely addressed by NETL-RUA and are broadly focused on investigation of the degradation processes of anode-electrolyte-cathode components and cathode materials and microstructural engineering. The research approach for each component task is targeted to address program technology development goals, especially with regard to reducing stack costs, increasing cell efficiency, and increasing stack longevity. The ultimate goal of these research and development efforts is to transfer technology that facilitates commercial acceptance of SOFC technology.

04: FWP-40552
SECA CORE TECHNOLOGY PROGRAM

Jeff Stevenson and Brian Koeppel, Pacific Northwest National Laboratory

2012 Technology Readiness Level: 3–4
DOE Funding: $55,889,667
Cost Share: $0
Duration: 10/01/1999 – 09/30/2014

Project Evaluation Score
10

The primary goal of this project is to develop, manufacture, and evaluate advanced SOFC component materials and computational tools.

05: FE0011769
SOLID OXIDE FUEL CELL POWER SYSTEM DEVELOPMENT
Rick Kerr, Delphi Automotive Systems, LLC

2012 Technology Readiness Level: N/A
DOE Funding: $5,100,027
Cost Share: $1,275,007
Duration: 10/01/2013 – 03/31/2015

Project Evaluation Score
8

The general focus of this project is the research and development of SOFC cell, stack, and system technology. Specifically, Delphi will improve the performance, robustness, and reliability of their technology and systems while testing and evaluating pre-commercial systems in an environment simulating their entry into service product.

06: FE0012077
SECA COAL-BASED SYSTEMS
Richard W. Goetller, LG Fuel Cell Systems, Inc.

2012 Technology Readiness Level: N/A
DOE Funding: $5,100,000
Cost Share: $1,275,000
Duration: 10/01/2013 – 03/31/2015

Project Evaluation Score
10

This project comprises laboratory development and testing of SOFC cells and stacks to advance and validate the reliability, robustness, and endurance of LG Fuel Cell Systems' (LGFCS) SOFC technology. LGFCS utilizes its integrated planar segmented-in-series SOFCs at pressures of up to seven atmospheres to achieve higher volumetric power densities. LGFCS will focus on advancing cell and stack materials and designs to create more stable and less expensive SOFC stacks and then test them at various scales to establish a preferred set of materials, which will undergo a block-scale metric test.

07: FE0011691
SOFC SYSTEMS WITH IMPROVED RELIABILITY AND ENDURANCE

Hossein Ghezel-Ayagh, FuelCell Energy, Inc.

2012 Technology Readiness Level: N/A
DOE Funding: $5,100,000
Cost Share: $1,275,000
Duration: 10/01/2013 – 03/31/2015

Project Evaluation Score

8

The specific technical objective of this project is to demonstrate, via analyses and testing, progress toward adequate stack life (four years) and performance stability (0.2 percent per 1,000 hours degradation) in a low-cost SOFC stack design. The work will focus on cell and stack materials and designs, balance-of-plant improvements to extend stack life and limit degradation, and performance evaluation covering operating conditions and fuel compositions anticipated for commercially-deployed systems.

APPENDIX A: ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Definition
AESD	ASME Advanced Energy Systems Division
AIAA	American Institute of Aerospace and Aeronautics
ASME	American Society of Mechanical Engineers
CCC	Copyright Clearance Center
CCS	carbon capture and storage
CCUS	carbon capture, utilization, and storage
CO_2	carbon dioxide
DG	distributed generation
DOE	U.S. Department of Energy
FY	fiscal year
HHV	higher heating value
IGFC	integrated gasification fuel cell
IPO	Independent Professional Organization
kW	kilowatt
kWe	kilowatt-electric
LGFCS	LG Fuel Cell Systems
LTI	Leonardo Technologies, Inc.
MW	megawatt
MWe	megawatt-electric
NETL	National Energy Technology Laboratory
OPPB	Office of Program Performance & Benefits
ORR	oxygen reduction and reaction
PI	principal investigator
PNNL	Pacific Northwest National Laboratory
R&D	research and development
RD&D	research, development, and demonstration
RUA	Regional University Alliance
scfm	standard cubic feet per minute
SECA	Solid State Energy Conversion Alliance
SOFC	solid oxide fuel cell
syngas	synthesis gas
TRL	Technology Readiness Level

APPENDIX B: PEER REVIEW EVALUATION CRITERIA FORM

U.S. DEPARTMENT OF ENERGY (DOE)
NATIONAL ENERGY TECHNOLOGY LABORATORY

FY14 SOLID OXIDE FUEL CELLS PEER REVIEW

APRIL 16–18, 2014

Project Title:	
Performer:	
Name of Peer Reviewer:	

The following pages contain the criteria used to evaluate each project. Each criterion is accompanied by multiple characteristics to further define the topic. Each Reviewer is expected to independently assess the provided material for each project, considering the Evaluation Criteria on the following page. Prior to the meeting, the Reviewers will independently create a list of strengths and weaknesses for each project based on the materials provided.

<u>At the meeting, the Facilitator and/or Panel Chairperson will lead the Peer Review Panel, in identifying consensus strengths, weaknesses, overall score, and prioritized recommendations for each project.</u> The consensus strengths and weaknesses shall serve as a basis for the determination of the overall project score in accordance with the Rating Definitions and Scoring Plan detailed on the following page.

A **strength** is an aspect of the project that, when compared to the evaluation criterion, reflects positively on the probability of successful accomplishment of the project's goals and objectives.

A **weakness** is an aspect of the project that, when compared to the evaluation criterion, reflects negatively on the probability of successful accomplishment of the project's goals and objectives.

Consensus strengths and weaknesses shall be characterized as either "major" or "minor." For example, a weakness that presents a significant threat to the likelihood of achieving the project's stated technical goals and supporting objectives should be considered "major," whereas relatively less significant opportunities for improvement are considered "minor.

A **recommendation** shall emphasize an action that will be considered by the project team and/or DOE to be included as a milestone for the project to correct or mitigate the impact of weaknesses, or expand upon a project's strengths. A recommendation should have as its basis one or more strengths or weaknesses. Recommendations shall be *ranked* from most important to least, based on the major/minor strengths/weaknesses.

Per the Independent Professional Organization (IPO) request, Reviewers are to record their individual strengths, weaknesses, recommendations and general comments under the

Reviewer Comments section of this form (page 3). However, only the panel's consensus remarks/scores will be used in the IPO-generated reports.

EVALUATION CRITERIA	
1	**Degree to which the project, if successful, supports the program's near- and/or long-term goals** • Clear project performance and/or cost/economic* objectives are present, appropriate for the maturity of the technology, and support the program goals. • Technology is ultimately technically and/or economically viable for the intended application.
2	**Degree of project plan technical feasibility** • Technical gaps, barriers and risks to achieving the project performance and/or cost objectives* are clearly identified. • Scientific/engineering approaches have been designed to overcome the identified technical gaps, barriers and risks to achieve the project performance and/or cost/economic objectives*.
3	**Degree to which progress has been made towards the stated project performance and cost/economic* objectives** • Milestones and reports effectively enable progress to be tracked. • Reasonable progress has been made relative to the established project schedule and budget.
4	**Degree to which the project plan-to-complete assures success** • Remaining technical work planned is appropriate, in light of progress to date and remaining schedule and budget. • Appropriate risk mitigation plans exist, including Decision Points if appropriate.
5	**Degree to which there are sufficient resources to successfully complete the project** • There is adequate funding, facilities and equipment. • Project team includes personnel with needed technical and project management expertise. • The project team is engaged in effective teaming and collaborative efforts, as appropriate.

* Projects that do not have cost/economic objectives should be evaluated on performance objectives only.

RATINGS DEFINITIONS AND SCORING PLAN

The panel will be required to assign a consensus score to the project, after strengths and weaknesses have been agreed upon. Intermediate scores are *not* acceptable. The overall project score must be justified by, and consistent with, the identified strengths and weaknesses.

RATING DEFINITIONS	
10	**Excellent -** Several major strengths; no major weaknesses; few, if any, minor weaknesses. Strengths are apparent and documented.
8	**Highly Successful -** Some major strengths; few (if any) major weaknesses; few minor weaknesses. Strengths are apparent and documented, and outweigh identified weaknesses.
5	**Adequate -** Strengths and weaknesses are about equal in significance.
2	**Weak -** Some major weaknesses; many minor weaknesses; few (if any) major strengths; few minor strengths. Weaknesses are apparent and documented, and outweigh strengths identified.
0	**Unacceptable -** No major strengths; many major weaknesses. Significant weaknesses/deficiencies exist that are largely insurmountable.

REVIEWER COMMENTS

Per the IPO request, Reviewers are to record their individual strengths, weaknesses, recommendations and general comments in the space provided below. However, only the panel's consensus remarks/scores will be used in the IPO-generated reports.

STRENGTHS A **strength** is an aspect of the project that, when compared to the evaluation criterion, reflects positively on the probability of successful accomplishment of the project's goals and objectives.
WEAKNESSES A **weakness** is an aspect of the project that, when compared to the evaluation criterion, reflects negatively on the probability of successful accomplishment of the project's goals and objectives.
RECOMMENDATIONS A **recommendation** shall emphasize an action that will be considered by the project team and/or DOE to be included as a milestone for the project to correct or mitigate the impact of weaknesses or expand upon a project's strengths. A recommendation should have as its basis one or more strengths or weaknesses. Recommendations shall be *ranked* from most important to least, based on the major/minor strengths/weaknesses.
GENERAL COMMENTS

APPENDIX C: TECHNOLOGY READINESS LEVEL DESCRIPTIONS

Research, Development, and Demonstration (RD&D) projects can be categorized based on the level of technology maturity. Listed below are nine (9) TRLs of RD&D projects managed by the NETL. These TRLs provide a basis for establishing a rational and structured approach to decision-making and identifying performance criteria that must be met before proceeding to the next level.

TRL	DOE-FE Definition	DOE-FE Description
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active R&D is initiated. This includes analytical and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology (e.g., individual technology components have undergone laboratory-scale testing using bottled gases to simulate major flue gas species at a scale of less than 1 scfm).
4	Component and/or system validation in a laboratory environment	A bench-scale prototype has been developed and validated in the laboratory environment. Prototype is defined as less than 5% final scale (e.g., complete technology process has undergone bench-scale testing using synthetic flue gas composition at a scale of approximately 1–100 scfm).
5	Laboratory-scale similar-system validation in a relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Prototype is defined as less than 5% final scale (e.g., complete technology has undergone bench-scale testing using actual flue gas composition at a scale of approximately 1–100 scfm).
6	Engineering/pilot-scale prototypical system demonstrated in a relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. Pilot or process-development-unit scale is defined as being between 0 and 5% final scale (e.g., complete technology has undergone small pilot-scale testing using actual flue gas composition at a scale equivalent to approximately 1,250–12,500 scfm).
7	System prototype demonstrated in a plant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Final design is virtually complete. Pilot or process- development-unit demonstration of a 5–25% final scale or design and development of a 200–600 MW plant (e.g., complete technology has undergone large pilot-scale testing using actual flue gas composition at a scale equivalent to approximately 25,000–62,500 scfm).
8	Actual system completed and qualified through test and demonstration in a plant environment	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include startup, testing, and evaluation of the system within a 200–600 MW plant CCS/CCUS operation (e.g., complete and fully integrated technology has been initiated at full-scale demonstration including startup, testing, and evaluation of the system using actual flue gas composition at a scale equivalent to approximately 200 MW or greater).
9	Actual system operated over the full range of expected conditions	The technology is in its final form and operated under the full range of operating conditions. The scale of this technology is expected to be 200–600 MW plant CCS/CCUS operations (e.g., complete and fully integrated technology has undergone full-scale demonstration testing using actual flue gas composition at a scale equivalent to approximately 200 MW or greater).

APPENDIX D: MEETING AGENDA

AGENDA

FY14 Solid Oxide Fuel Cells Peer Review

April 16 – 18, 2014

Sheraton Station Square
Pittsburgh, PA

Wednesday, April 16, 2014 – Waterfront Room

7:00 – 8:00 a.m.	**Registration – Admiral Foyer**
8:00 – 9:00 a.m.	**Peer Review Panel Kick-Off Meeting** Open to National Energy Technology Laboratory (NETL) and ASM International staff only - Review of ASM International Process – Stanley C. Theobald, ASM International - Role of ASM International Panel Chair – Ravi Prasad, Helios-NRG, LLC - Peer Review Process Overview – David Wildman, Leonardo Technologies, Inc. (LTI) - Meeting Logistics – David Wildman, LTI
9:00 – 9:15 a.m.	**Technology Manager and Panel Q&A** Open to NETL and ASM International staff only - Solid Oxide Fuel Cells Technology Manager – Shailesh Vora, NETL
9:15 – 9:30 a.m.	**BREAK**
9:30 – 10:15 a.m.	**Office of Program Performance & Benefits (OPPB) Support to the Solid Oxide Fuel Cells Program – Overview** *Kristin Gerdes,* **National Energy Technology Laboratory** *Dale Keairns and Arun Iyengar,* **Booz Allen Hamilton**
10:15 – 10:35 a.m.	Q&A/Discussion
10:35 – 11:20 a.m.	**01 – Project # OPPB/BD-1** – Assessment of Market Potential for Fuel Cells in Distributed Generation Applications *Kristin Gerdes,* **National Energy Technology Laboratory** *Dale Keairns and Arun Iyengar,* **Booz Allen Hamilton**
11:20 – 11:40 a.m.	Q&A/Discussion
11:40 – 12:45 p.m.	**Lunch (on your own)**
12:45 – 1:15 p.m.	**02 – Project # FE0009675** – Fundamental Understanding of Oxygen Reduction and Reaction Behavior and Developing High Performance and Stable Cathodes *Xingbo Liu,* **West Virginia University Research Corporation**
1:15 – 1:45 p.m.	Q&A
1:45 – 3:00 p.m.	Discussion
3:00 – 3:15 p.m.	**BREAK**

Wednesday, April 16, 2014 – Waterfront Room

3:15 – 3:45 p.m.	**03 – Project # FWP-2012.03.04 Tasks 1 and 2** – NETL-RUA Fuel Cells Initiative: Task 1, Cell and Stack Degradation; Task 2, Cathode Materials and Microstructural Engineering *Kirk Gerdes,* **National Energy Technology Laboratory**
3:45 – 4:15 p.m.	Q&A
4:15 – 5:30 p.m.	Discussion

Thursday, April 17, 2014 – Waterfront Room

7:00 – 8:00 a.m.	**Registration – Admiral Foyer**
8:00 – 8:30 a.m.	**04 – Project # FWP-40552** – SECA Core Technology Program *Jeff Stevenson and Brian Koeppel,* **Pacific Northwest National Laboratory**
8:30 – 9:00 a.m.	Q&A
9:00 – 10:15 a.m.	Discussion
10:15 – 10:30 a.m.	**BREAK**
10:30 – 11:00 a.m.	**05 – Project # FE0011769** – Solid Oxide Fuel Cell Power System Development *Rick Kerr,* **Delphi Automotive Systems, LLC**
11:00 – 11:45 a.m.	Q&A
11:45 – 1:00 p.m.	Discussion
1:00 – 2:00 p.m.	**Lunch (on your own)**
2:00 – 2:30 p.m.	**06 – Project # FE0012077** – SECA Coal-Based Systems *Richard W. Goetller,* **LG Fuel Cell Systems, Inc.**
2:30 – 3:15 p.m.	Q&A
3:15 – 4:30 p.m.	Discussion

Friday, April 18, 2014 – Waterfront Room

7:00 – 8:00 a.m.	**Registration – Admiral Foyer**
8:00 – 8:30 a.m.	**07 – Project # FE0011691** – SOFC Systems with Improved Reliability and Endurance *Hossein Ghezel-Ayagh,* **FuelCell Energy, Inc.**
8:30 – 9:15 a.m.	Q&A
9:15 – 10:30 a.m.	Discussion
10:30 – 10:45 a.m.	**BREAK**
10:45 – 12:15 p.m.	**Wrap-up Session**

APPENDIX E: PEER REVIEW PANEL MEMBERS

Ravi Prasad, Ph.D. – Panel Chair
Helios-NRG, LLC—President

- Principal investigator (PI) of DOE Small Business Technology Transfer Phase 2 project developing step-change technology to recover helium from low-purity sources using a new separation technology in a hybrid process
- PI of new algae technology for carbon dioxide (CO_2) mitigation, bio-fuel production, and water remediation applications
- Consulted with DOE in application reviews for “CCS from Industrial Sources and Innovative Concepts for Beneficial CO_2 Use,” “Clean Coal Power Initiative–Round 3,” and “Large-Scale Industrial CCS Projects”
- Panelist in 10 NETL peer reviews and Chair of four peer reviews
- Consultant to Praxair on sustainability initiative
- Provided consultation services to industrial clients in clean energy, natural gas processing, CO_2, helium recovery, membrane technology, cryogenic, and other gas separation processes

Ravi Prasad of Helios-NRG, LLC and formerly a corporate fellow of Praxair Inc., has 60 U.S. patents and broad industrial experience in developing and commercializing new technologies, launching technology programs ($2 million–$50 million), supporting business development, building cross-functional teams, and setting up joint development alliances. Mr. Prasad established over 25 alliances for development and commercialization; recruited, mentored, and led a world-class team of 35 scientists and engineers; and established and managed Praxair’s polymeric membrane process skill center and helped assess and later integrate new acquisition. He is a founding member of a major international alliance involving Praxair and five Fortune-500 companies to develop step-change synthesis gas (syngas) technology for gas-to-liquids.

Dr. Prasad also established and led programs for ceramic membrane oxygen technology; co-developed proposals to secure major DOE programs in syngas, worth $35 million, and in oxygen, worth $20 million; identified novel, solid-state oxygen generation technology; and conceived and implemented a coherent corporate strategy in nanotechnology. He developed Praxair’s skill center in ceramic ion transport membranes, and led programs in integrated gasification combined cycle, combustion, oxygen, and solid oxide fuel cell afterburner.

Dr. Prasad’s technical areas of expertise include membranes and separations, hydrogen and helium, industrial gas production and application, ceramic membranes and solid oxide fuel cells, new technology development, technology roadmapping, intellectual property strategy development, technology due diligence, combustion, nanotechnology, gas-to-liquids, coal-to-liquids, and silane pyrolysis reactors.

Dr. Prasad has a B.S. in mechanical engineering from the Indian Institute of Technology in Kanpur, India; and an M.S. and Ph.D. in mechanical engineering and chemical engineering from the State University of New York, Buffalo.

Thomas L. Cable, Ph.D.

Dr. Cable is a specialist in solid oxide fuel cells (SOFCs), regenerative fuel cells, and catalytic reforming, with 30 years of laboratory and project management experience. His areas of expertise include anode and cathode compositions and nanostructures, solid electrolytes, sulfur-tolerant anodes and catalysts for steam reforming of heavy hydrocarbons (JP8 and diesel), and mixed ionic/electronic-conducting ceramic membranes for oxygen separation. Dr. Cable is currently consulting through his company TLCell, LLC.

Most recently Dr. Cable was a Senior Development Professional at Praxair, developing oxygen transport membranes, a technology he co-invented at BP in the late 1980s. Prior to his position at Praxair, Dr. Cable was Chief Scientist in Solid Oxide Fuels Cells for the Ceramics Branch at NASA Glenn/U. Toledo, from 2003 to 2011. In this position, he served as the technical lead in the development of all-ceramic SOFC designs for aeronautic applications. Prior to this position, Dr. Cable was Chief Scientist at SOFCo (McDermott Technology, Inc.) from 1999 to 2003, where he was principal investigator in cell development of the SOFCo fuel cell stack design. In addition, he was co-director of the U.S. Department of Energy, Solid State Energy Conversion Alliance (SECA), a 10-year, $75 million contract for the development of a 10-kW auxiliary power unit. Dr. Cable was a research scientist at BP Chemicals from 1997 to 1999; a group leader in materials research at Technology Management, Inc., from 1993 to 1997; a Senior Project Leader at BP America, Inc., from 1987 to 1992; and a Senior Project Engineer at Standard Oil Co. of Ohio from 1984 to 1987.

Dr. Cable holds 28 U.S. patents for inventions related to SOFC and mixed ionic-electronic conducting membranes. Dr. Cable has presented at numerous conferences, has published eight reports and journal articles, and is a member of the American Ceramic Society (Electronics Division). Dr. Cable received a B.S. in chemistry and chemical engineering and a Ph.D. in chemical and fuels engineering from the University of Utah. He completed a post-doctoral fellowship at Brigham Young University, studying Fischer-Tropsch Catalysis for the conversion of carbon monoxide and hydrogen to gasoline, under the direction of Professor Calvin Bartholomew. His current research focus is in fuel processing and reforming catalysis.

Minking K. Chyu, Ph.D.

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 focus is thermo-fluid issues related to power and propulsion system, material processing, microsystem technology, transport phenomena, energy and power systems, gas turbines, and fuel cells. 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 microstructures.

Dr. Chyu has received numerous honors and awards, including four NASA Certificates of Recognition for his contribution on space shuttle main engine program, Air Force Summer Research Fellow, Department of Energy Oak Ridge Research Fellow, and DOE Advanced-Turbine-System Faculty Fellow. He is a Fellow of the American Society of Mechanical Engineers (ASME), Associate Fellow of American Institute of Aerospace and Aeronautics (AIAA), and a U.S. delegate to the Scientific Council of the International Centre of Heat and Mass Transfer. He was named the Engineer of the Year by the ASME Pittsburgh Chapter in 2002. He serves as an associate editor for the *Journal of Heat Transfer*, ASME, advisory board member for the *International Journal of Fluid Machinery and Systems*, a guest editor for *AIAA*

Journal of Propulsion, and a foreign editor for the *International Journal of Chinese Institute of Mechanical Engineers*.

Dr. Chyu has over 130 journal publications and over 150 symposium and conference papers, has been conference chair or organizer of nearly 30 conferences, served as an invited lecturer on more than 40 occasions, has won over 60 grants, and has graduated 14 Ph.D. and more than 20 M.S. students.

Dr. Chyu received a B.S. in nuclear engineering at the National Tsing Hua University in Taiwan, an M.S. in applied mechanics at the University of Cincinnati, and a Ph.D. in mechanical engineering from the University of Minnesota.

Wayne Huebner, Ph.D.

Dr. Wayne Huebner is a Professor of Ceramic Engineering, and the Chairman of the Materials Science and Engineering Department at the Missouri University of Science and Technology in Rolla, MO. Prior to this position he served as the Vice Provost for Research from 2001–2007. The author of over 100 papers, monographs, and book chapters, he has been actively involved in the preparation and characterization of electronic ceramics. Much of his research is focused on the use of dielectrics, ionic and mixed conductors, piezoelectrics, electrostrictive materials for multilayer capacitors, solid oxide fuel cells, gas separation membranes, and phased linear array transducers for intravascular imaging. He has graduated 10 Ph.D. students and 15 M.S. students. Huebner has received S&T's Faculty Excellence Award five times, the Outstanding Teacher Award four times, and was named the Outstanding Faculty Member in Ceramic Engineering five consecutive years. He has been a continuous member of the Electronics Division of the American Ceramic Society since 1983, serving in many capacities including all offices of the Ceramic Educational Council, an organizer of various symposia, and Associate Editor of the *Journal of the American Ceramic Society*.

Dr. Huebner received his B.S and Ph.D. in ceramic engineering from the University of Missouri-Rolla.

Michael R. von Spakovsky, Ph.D.

Dr. von Spakovsky has over 27 years of teaching and research experience in academia and over 17 years of industry experience in mechanical engineering, power utility systems, aerospace engineering, and software engineering. He received his B.S. in Aerospace Engineering in 1974 from Auburn University and his M.S and Ph.D. in Mechanical Engineering in 1980 and 1986, respectively, from the Georgia Institute of Technology. While at Auburn he worked for 3½ years at NASA in Huntsville, AL, and from 1974 to 1984 and from 1987 to 1989 worked in the power utility industry first as an engineer and then as a consultant. From 1989 to 1996, Dr. von Spakovsky worked as both an educator and researcher at the Swiss Federal Institute of Technology in Lausanne, Switzerland, where he led a research team in the modeling and systems integration of complex energy systems and taught classes in the thermodynamics of indirect and direct energy conversion systems (including fuel cells).

In January of 1997, Dr. von Spakovsky joined the Mechanical Engineering faculty at Virginia Tech as Professor and Director of the Energy Management Institute (now the Center for Energy Systems Research). He teaches undergraduate and graduate level courses in thermodynamics and intrinsic quantum thermodynamics, kinetic theory and the Boltzmann equation, fuel cell systems, and energy system design. His research interests include computational methods for modeling and optimizing complex energy systems; methodological approaches (with and without sustainability and uncertainty considerations) for the integrated synthesis, design, operation, and control of such systems (e.g., stationary power systems grid/microgrid/producer/storage and district heating/cooling networks, high performance aircraft systems); theoretical and applied thermodynamics with a focus on intrinsic quantum thermodynamics applied to nanoscale and microscale reactive and non-reactive systems; and fuel cell applications for both transportation and centralized, distributed, and portable power generation and cogeneration.

Dr. von Spakovsky has published widely in scholarly journals, conference proceedings, etc., (over 210 publications) and has given talks, keynote lectures, seminars, and short courses (e.g., on fuel cells and intrinsic quantum thermodynamics) worldwide. Included among his various professional activities and awards is senior member of the American Institute of Aerospace and Aeronautics; *Fellow of the ASME*; the *2012 ASME Edward F. Obert Award*; the *2005*, *2008*, and *2012 ASME Advanced Energy Systems Division (AESD) Best Paper Awards*; the *ASME AESD Lifetime Achievement Award*; former Chair of the *Executive Committee* for the ASME AESD, elected member of Sigma Xi and Tau Beta Pi, Associate Editor of the *International Journal of Fuel Cell Science and Technology*, former Editor-in-Chief (11-year tenure) of the *International Journal of Thermodynamics*, and Chair of the *Executive Committee* for the *International Center of Applied Thermodynamics*.