OVERVIEW REPORT

DOE/NETL Clean Coal Research Program
Solid Oxide Fuel Cells Program
FY2016 Peer Review Meeting

Pittsburgh, Pennsylvania
April 25-26, 2016

ASM INTERNATIONAL

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OVERVIEW REPORT
CLEAN COAL RESEARCH PROGRAM
SOLID OXIDE FUEL CELLS PROGRAM
FY2016 PEER REVIEW MEETING

Pittsburgh, Pennsylvania
April 25-26, 2016

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DISCLAIMER

The work performed on this task/subtask was completed under Leonardo Technologies, Inc. (LTI), Prime Contract DE-FE0004002 (Subtask 300.01.05) for DOE-NETL.

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INTRODUCTION AND BACKGROUND

The U.S. Department of Energy (DOE) Office of Clean Coal and Carbon Management develops innovative, near-zero-emissions technologies that are integrated with carbon capture and storage (CCS) and improved fuel conversion efficiency through research and development (R&D) in the Advanced Energy Systems (AES) program. The R&D portfolio includes Advanced Combustion Systems, Gasification Systems, Coal and Coal-Biomass to Liquids, Advanced Turbines, and Solid Oxide Fuel Cells (SOFC) energy conversion systems. The AES program's key efforts are directed at improving fuel conversion efficiencies within the plant boundary by increasing plant availability, reducing water consumption, and achieving ultra-low emissions of traditional pollutants. Many of these technologies require new approaches to electricity generation, and simultaneously achieve higher efficiencies while capturing carbon dioxide (CO_2) as part of the conversion process. The research is targeted at improving overall system efficiency, reducing capital and operating costs, and enabling affordable carbon capture. The National Energy Technology Laboratory-managed (NETL) SOFC program is focused on developing novel, fuel-cell-powered atmospheric and pressurized systems that produce electric power from coal using integrated coal gasification with carbon capture.

SOFCs are a transformational technology whose inherent characteristics make them uniquely suitable to address the environmental, climate change, and water concerns associated with fossil-fuel-based—and in particular coal-based—electric power generation. SOFCs are scalable and efficient (not subject to Carnot cycle limitations), produce low emissions (e.g., nitrogen oxides) compared to combustion-based electrical power generation technologies (due to lower operating temperatures), and are fuel-flexible, allowing for a common module design that can be deployed for use with either coal-derived synthesis gas (syngas) or natural gas. The SOFC program is focused on the R&D needed to enable generation of efficient, cost-effective electricity from coal and natural gas with near-zero atmospheric emissions of CO_2 and air pollutants, as well as minimal water use in central power generation applications that can be integrated with CCS. The program is in the process of developing highly efficient, ultralow emission, fuel-flexible SOFC technology that can exploit domestic fossil fuel resources, maintain sound environmental stewardship, and contribute to a secure, clean energy future.

The SOFC program is developing technologies in three areas to improve performance, enhance durability, reduce cost, and demonstrate SOFC power systems: 1) Anode-Electrolyte-Cathode (AEC) Development, 2) Atmospheric Pressure Systems, and 3) Pressurized Systems.

- **Cell Technology**—Research is focused on the cell-related technologies critical to the commercialization of SOFC technology. Electrochemical performance, durability, and reliability of the SOFC are the key determinants in establishing the technical and economic viability of SOFC power systems. Efforts to optimize these attributes focus on the design of specific cell components—namely the anode, electrolyte, cathode, and interconnect—which are the primary research emphasis of the Cell Technology key technology area. Other research projects within the portfolio focus on various technical challenges to commercialization such as advanced materials development, materials characterization, anode contaminants, and failure analysis. The data and results are available to all Industry Teams, ensuring broad technology development and avoiding the duplication of R&D activities.

- **Core Technology**—This key technology area conducts applied R&D on technology issues— exclusive of the cell components—that are critical to the commercialization of SOFC technology. Efforts are focused on laboratory and bench-scale R&D that improves the reliability, robustness, endurance, and cost of the SOFC stack; identifies and mitigates stack-related degradation issues; develops and optimizes computational tools and models; and improves the reliability, robustness, endurance, and cost of balance-of-plant components.
- **Systems Development**—Research, development, and demonstration (RD&D) within this key technology area focuses on the design, scale-up, and integration of SOFC technology, ultimately resulting in SOFC modules suitable to serve as the building blocks for distributed generation, commercial, and utility-scale power systems. Project participants (i.e., Industry Teams) are independently developing unique and proprietary SOFC technology suitable for either syngas or natural-gas fueled applications. The Industry Teams are responsible for the design and manufacture of the fuel cells, hardware development, manufacturing process development, commercialization of the technology, and market penetration. These developers also focus on the scale-up of cells and stacks for aggregation into fuel cell modules and the validation of technology that evolves from the Cell Technology and Core Technology areas. This key technology area supports laboratory-scale stack tests, proof-of-concept systems, pilot-scale demonstrations, and deployment of commercial power systems. The developers have the opportunity to determine relevant R&D topics based on their design-specific experience and needs, and are held to a common set of performance and cost metrics.

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) 2016 SOFC Program 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. (LTI), ASM International convened a panel of leading academic and industry experts on April 25–26, 2016, to conduct a two-day peer review of selected NETL-supported SOFC program research projects.

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

The total funding of the six projects reviewed, over the duration of the projects, is $20,939,775. The funding and duration of the six projects that were the subject of this peer review are provided in Table 1.

TABLE 1. SOLID OXIDE FUEL CELLS PROGRAM PROJECTS REVIEWED

Reference Number	Project Number	Title	Lead Organization	Total Funding		Project Duration	
				DOE	Cost Share	From	To
01	FWP-FY16 Fuel Cells	Fuel Cells	NETL	$6,500,000	$0	10/1/2014	9/30/2020
02	FE0023385	Materials and Approaches for the Mitigation of SOFC Cathode Degradation in SOFC Power Systems	University of Connecticut	$1,050,000	$264,625	10/1/2014	9/30/2017
03	FE0026098	Advanced Materials and Manufacturing Processes for MW-Scale SOFC Power Systems for Improved Stack Reliability, Durability, and Cost	LG Fuel Cell Systems, Inc.	$2,500,000	$625,150	10/1/2015	9/30/2017
04	FWP-FEAA121	Reliability of Materials and Components for Solid Oxide Fuel Cells	Oak Ridge National Laboratory	$875,000	$0	10/1/2014	9/30/2016
05	FE0026093	Innovative SOFC Technologies	FuelCell Energy Inc.	$2,500,000	$625,000	10/1/2015	9/30/2017
06	FWP-66841	SECA Core Technology Program - PNNL	Pacific Northwest National Laboratory	$6,000,000	$0	10/1/2014	9/30/2016

OVERVIEW OF THE PEER REVIEW PROCESS

The U.S. Department of Energy (DOE) 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) 2016, ASM International was invited to provide an independent, unbiased, and timely peer review of selected projects within the DOE/NETL Solid Oxide Fuel Cells (SOFC) program. The peer review of selected projects within the SOFC program was designed to comply with requirements from the Office of Management and Budget.

On April 25–26, 2016, ASM International convened a panel of five leading academic and industry experts to conduct a two-day peer review of six research projects supported by the NETL SOFC program. Throughout the peer review meeting, these recognized technical experts provided recommendations on how to improve the management, performance, and overall results of each research project.

In consultation with NETL representatives, 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. (LTI).

Pre-Meeting Preparation

Several weeks before the peer review, each project team submitted a Project Technical Summary and the final PowerPoint slide deck they would present at the peer review meeting. Additionally, the appropriate Federal Project Manager (FPM) provided the project management plan and other relevant materials, including quarterly and annual reports (if applicable), and published journal articles (if applicable) that would help the peer review panel evaluate each project. The panel received all of these materials prior to the peer review meeting via a secure and confidential peer review SharePoint site, which enabled the panel members to fully prepare for the meeting 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/WebEx was held with the review panel and ASM International support staff prior to the meeting to review the peer review process and allow for the Portfolio Manager and Team Supervisor of the SOFC program to provide an overview of the program goals and objectives.

Peer Review Meeting Proceedings

At the meeting, each research team made an uninterrupted 30-minute PowerPoint presentation that was followed by a 45-minute question-and-answer session with the panel and a 75-minute panel discussion and evaluation of each project. The time allotted for the project presentation, 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.

To facilitate the evaluation process, LTI provided panelists with laptop computers during the review 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’s consensus score for each project was based on the following definitions (the panel was welcome to assign any integer value ranging from 0 to 10):

- 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 2014. The technology readiness level (TRL) of projects assessed in 2014 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 2014.

SUMMARY OF KEY FINDINGS

This section summarizes the overall key findings of the six projects evaluated at the fiscal year (FY) 2016 Solid Oxide Fuel Cells (SOFC) Program Peer Review.

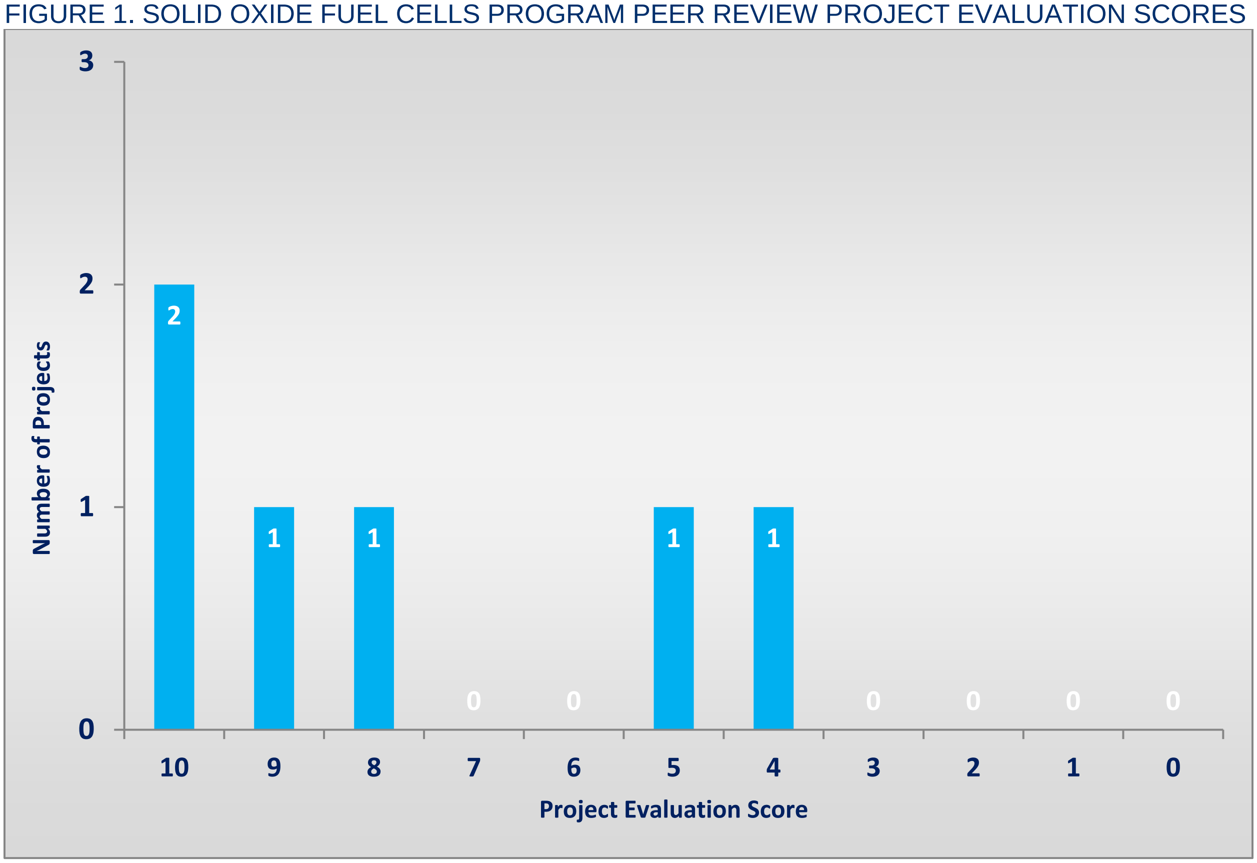
Overview of Project Evaluation Scores

The panel assigned a consensus score for each project based on the following definitions (the panel was welcome to assign any integer value ranging from 0 to 10):

- 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 indicates that a specific project was viewed as at least adequate by the panel. The number of projects given each project evaluation score is shown in Figure 1.

FIGURE 1. SOLID OXIDE FUEL CELLS PROGRAM PEER REVIEW PROJECT EVALUATION SCORES



PROJECT SYNOPSES

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

01: FWP-FY16 FUEL CELLS
FUEL CELLS

Gregory Hackett, National Energy Technology Laboratory

Technology Readiness Level: 3	***DOE Funding:*** $6,500,000
Duration: 10/1/2014 – 9/30/2020	***Cost Share:*** $0

The cell and stack degradation effort is intended to compile complete knowledge of prominent degradation modes in anode-electrolyte-cathode (AEC) systems, quantify the relative importance of each identified mode, and generate a comprehensive degradation modeling tool that will serve as the basis for comparison to other prominent stack component degradation modes. Degradation analysis will be pertinent to a wide range of operating conditions relevant to commercial solid oxide fuel cells (SOFCs) and will be completed for both hydrogen- and syngas-fueled conditions.

02: FE0023385
MATERIALS AND APPROACHES FOR THE MITIGATION OF SOFC CATHODE DEGRADATION IN SOFC POWER SYSTEMS

Prabhakar Singh, University of Connecticut

Technology Readiness Level: 3	***DOE Funding:*** $1,050,000
Duration: 10/1/2014 – 9/30/2017	***Cost Share:*** $264,625

The University of Connecticut will develop and validate reliable, cost-effective approaches for minimizing/mitigating solid oxide fuel cell (SOFC) cathode (lanthanum strontium manganite [LSM] and lanthanum strontium cobalt ferrite [LSCF]) degradation through the incorporation of reliable materials and architectures to inhibit long-term detrimental solid-solid and solid-gas interactions. This work will develop and demonstrate the viability of the application of a cost-effective chromium getter to capture the chromium species originating from the metallic stack and balance-of-plant components. Cathode compositions will be modified to control and prevent oxide segregation and compound formation at the surface and interfaces during air exposure. Cathode contact layer modification will be developed to avoid chromium poisoning originating from metallic interconnects.

03: FE0026098
ADVANCED MATERIALS AND MANUFACTURING PROCESSES FOR MW-SCALE SOFC POWER SYSTEMS FOR IMPROVED STACK RELIABILITY, DURABILITY, AND COST

Charles Osborne, LG Fuel Cell Systems, Inc.

Technology Readiness Level: 3	***DOE Funding:*** $2,500,000
Duration: 10/1/2015 – 9/30/2017	***Cost Share:*** $625,150

LG Fuel Cell Systems, Inc. (LGFCS) will qualify a material and process solution for selected metallic components of an advanced integrated stack block for the entry-into-service product that will significantly reduce component cost and increase the reliability and endurance of LGFCS cell and stack technology. The project team expects this research to result in an optimized materials and processing solution that will significantly reduce component costs for a critical SOFC subsystem.

04: FWP-FEAA121
RELIABILITY OF MATERIALS AND COMPONENTS FOR SOLID OXIDE FUEL CELLS

Edgar Lara-Curzio, Oak Ridge National Laboratory

Technology Readiness Level: 3	***DOE Funding:*** $875,000
Duration: 10/1/2014 – 9/30/2016	***Cost Share:*** $0

Oak Ridge National Laboratory (ORNL) will enhance the reliability, robustness, and endurance of solid oxide fuel cell (SOFC) stacks to commercially viable levels by developing, verifying, and implementing methodologies for predicting the reliability of ceramic components for SOFCs. ORNL will also investigate the effect of creep deformation of anode materials (e.g., nickel yttria-stabilized zirconium [Ni-YSZ]) on the redistribution of stresses in cells and stacks and will develop and implement test methods for the evaluation of dissimilar material joints in SOFC stacks and experimentally determining their state of residual stresses.

05: FE0026093
INNOVATIVE SOFC TECHNOLOGIES

Hossein Ghezel-Ayagh, FuelCell Energy Inc.

Technology Readiness Level: 3	***DOE Funding:*** $2,500,000
Duration: 10/1/2015 – 9/30/2017	***Cost Share:*** $625,000

The goal of this cooperative agreement is to research and develop solid oxide fuel cell (SOFC) stack technology that has the potential to undercut current U.S. Department of Energy (DOE) cost targets by 50 percent. The pathways to reaching the project's objective consist of novel materials development; transformational manufacturing processes; high-performance cell components; and innovative, robust, and reliable stack designs leveraging advancements that have occurred in the DOE SOFC Program.

06: FWP-66841
SECA CORE TECHNOLOGY PROGRAM - PNNL

Jeff Stevenson and Brian Koeppel, Pacific Northwest National Laboratory

Technology Readiness Level: 3	***DOE Funding:*** $6,000,000
Duration: 10/1/2014 – 9/30/2016	***Cost Share:*** $0

This project will advance and accelerate the development of reliable, low-cost, fuel-flexible solid oxide fuel cell (SOFC) systems by developing advanced SOFC cell and stack component materials, cost-effective fabrication techniques, and computational tools. Important to this work is the evaluation and development of materials and manufacturing processes for various SOFC components (electrolyte, anode, cathode, interconnects, and seals) to improve long-term performance stability and reliability. In addition, this project will develop computational simulation and modeling to simulate thermal, mechanical, and electrical behavior of unit cells and large multi-cell stacks and to develop an understanding of their underlying mechanical and chemical degradation processes.

APPENDIX A: ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Definition
AEC	anode-electrolyte-cathode
AES	Advanced Energy Systems (NETL program)
AESD	ASME Advanced Energy Systems Division
AIAA	American Institute of Aeronautics and Astronautics
ASME	American Society of Mechanical Engineers
CCC	Copyright Clearance Center
CCS	carbon capture and storage
CO_2	carbon dioxide
DOE	U.S. Department of Energy
FPM	Federal Project Manager
FY	fiscal year
GaN	gallium nitride
HEMT	high-electron mobility transistor
HFET	heterojunction field-effect transistor
IEEE	Institute of Electrical & Electronics Engineers
InP	indium phosphide
IPO	independent professional organization
LGFCS	LG Fuel Cell Systems, Inc.
LSM	lanthanum strontium manganite
LSCF	lanthanum strontium cobalt ferrite
LTI	Leonardo Technologies, Inc.
MW	megawatt
NASA	National Aeronautics and Space Administration
NETL	National Energy Technology Laboratory
Ni-YSZ	nickel yttria-stabilized zirconium
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
R&D	research and development
RBTO	Reliability-Based Topological Optimization
RD&D	research, development, and demonstration
scfm	standard cubic feet per minute
SOFC	solid oxide fuel cell(s)
syngas	synthesis gas
TRL	technology readiness level
UCI	University of California, Irvine

APPENDIX B: PEER REVIEW EVALUATION CRITERIA FORM

PEER REVIEW EVALUATION CRITERIA AND GUIDELINES

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

Peer Review Title:	
Dates:	
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. To assist Reviewers in capturing their thoughts both before and during the meeting, an optional form is attached at the end of this document.

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. 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" during the panel's consensus discussion at the meeting. 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.

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 whole number scores are acceptable if the panel feels it is appropriate. 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.

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 National Energy Technology Laboratory (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

Monday, April 25, 2016 – Ellwood Room (Solid Oxide Fuel Cells Program)

7:00 – 8:00 a.m.	**Registration – 2nd Floor Foyer**
8:00 – 8:30 a.m.	**Peer Review Panel Kickoff Session – Solid Oxide Fuel Cells** Open to National Energy Technology Laboratory (NETL) and ASM International staff only - ASM International Welcome - Role of Panel Chair - Technology Manager / Division Director, Systems Engineering & Analysis (SEA) Team and Panel Question and Answer - Peer Review Process and Meeting Logistics
8:30 – 9:00 a.m.	**01 – Project # FWP-FY16 Fuel Cells** – Fuel Cells *Gregory Hackett* – **National Energy Technology Laboratory (NETL-ORD)**
9:00 – 9:45 a.m.	Q&A
9:45 – 11:00 a.m.	Discussion
11:00 – 12:00 p.m.	**Lunch (on your own)**
12:00 – 12:30 p.m.	**02 – Project # FE0023385** – Materials and Approaches for the Mitigation of SOFC Cathode Degradation in SOFC Power Systems *Prabhakar Singh* – **University of Connecticut**
12:30 – 1:15 p.m.	Q&A
1:15 – 2:30 p.m.	Discussion
2:30 – 2:45 p.m.	**BREAK**
2:45 – 3:15 p.m.	**03 – Project # FE0026098** – Advanced Materials and Manufacturing Processes for MW-Scale SOFC Power Systems for Improved Stack Reliability, Durability, and Cost *Charles Osborne* – **LG Fuel Cell Systems Inc.**
3:15 – 4:00 p.m.	Q&A
4:00 – 5:15 p.m.	Discussion

Tuesday, April 26, 2016 – Ellwood Room (Solid Oxide Fuel Cells Program)

7:00 – 8:00 a.m.	**Registration – 2nd Floor Foyer**
8:00 – 8:30 a.m.	**04 – Project # FWP-FEAA121** – Reliability of Materials and Components for Solid Oxide Fuel Cells *Edgar Lara-Curzio* – **Oak Ridge National Laboratory (ORNL)**
8:30 – 9:15 a.m.	Q&A
9:15 – 10:30 a.m.	Discussion
10:30 – 10:45 a.m.	**BREAK**
10:45 – 11:15 a.m.	**05 – Project # FE0026093**– Innovative SOFC Technologies *Hossein Ghezel-Ayagh* – **FuelCell Energy Inc. (FCE)**
11:15 – 12:00 p.m.	Q&A
12:00 – 1:15 p.m.	Discussion
1:15 – 2:15 p.m.	**Lunch (on your own)**
2:15 – 2:45 p.m.	**06 – Project # FWP-66841** – SECA Core Technology Program - PNNL *Jeff Stevenson and Brian Koeppel* – **Pacific Northwest National Laboratory (PNNL)**
2:45 – 3:30 p.m.	Q&A
3:30 – 4:45 p.m.	Discussion
4:45 – 5:00 p.m.	**BREAK**
5:00 – 6:00 p.m.	**Solid Oxide Fuel Cells Program Peer Review Wrap-up Session**

APPENDIX E: PEER REVIEW PANEL MEMBERS

Michael von Spakovsky, Ph.D. – Panel Chair

Dr. von Spakovsky has over 29 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 three and a half years at the National Aeronautics and Space Administration (NASA) in Huntsville, Alabama 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. He has published widely in scholarly journals and conference proceedings (over 220 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 Aeronautics and Astronautics (AIAA)*; *Fellow of the American Society of Mechanical Engineers (ASME)*; the *2014 ASME James Harry Potter Gold Medal*; 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 *ASME Journal of Electrochemical Energy Conversion and Storage;* and former Editor-in-Chief (11-year tenure) and now Honorary Editor of the *International Journal of Thermodynamics*.

Mehdi Anwar, Ph.D.

Dr. Mehdi Anwar is a full-time professor in the Electrical and Computer Engineering Department at the University of Connecticut, where he also serves as the director of the National Science Foundation funded Industry University Cooperative Research Center. Before that, in addition to his teaching responsibilities, he was the associate dean for Research & Graduate Education for the School of Engineering, served as the interim department head of the Electrical and Computer Engineering Department, was founding director for the Department of Homeland Security's Center of Excellence, and served as interim director of the Connecticut Global Fuel Cell Center. During a sabbatical leave in 2004, Anwar worked for the Sensors Directorate at

Hanscom Air Force Base, developing advanced metamorphic high-electron mobility transistors (HEMTs) and gallium nitride (GaN)-based heterojunction field-effect transistors (HFETs).

Dr. Anwar's research interests include localization of one-dimensional structures, transport and noise in semiconductors, impurity diagnostics in quantum-well devices, and power optimization in GaN-based devices and circuits. He also developed trap characterization methods for indium phosphide (InP) and GaN-based HEMTs and load-pull setups at W-band. Anwar's modeling interests include transport in DNA, silicon nanowires, quantum-well infrared photodetectors, stochastic quantum mechanics, and noise in quantum structures. Dr. Anwar led pioneering efforts to measure noise in metamorphic antimony-based compound-semiconductor HEMTs, and one of his designs was instrumental in the Air Force Research Laboratory's development of low-noise metamorphic HEMTs based on 0.15-micron gate technology. He also predicted that channel pinch-off would not occur in wide quantum-well devices.

Dr. Anwar has presented over 15 plenary and invited talks, published over 170 papers, co-authored three book chapters, and served as principal investigator or co-principal investigator on research grants and contracts worth over $4.4 million. Anwar is an editor for the Institute of Electrical & Electronics Engineers (IEEE) *Transactions on Electron Devices* and is conference chair of SPIE's international conference on Terahertz Physics, Devices and Systems: Advanced Applications in Industry and Defense. He is a member of Clarkson University's Engineering Advisory Council, IEEE's Electron Devices Society, and the Institute of Engineers in Bangladesh. Anwar is also a fellow of SPIE and a senior member of IEEE.

Dr. Anwar has a B.S. and M.S. in electrical and computer engineering from the Bangladesh University of Engineering and Technology and a Ph.D. in electrical and computer engineering from Clarkson University.

Jack Brouwer, Ph.D.

Dr. Jack Brouwer is associate professor in Mechanical and Aerospace Engineering at the University of California, Irvine (UCI). Through Dr. Brouwer's leadership, UCI's National Fuel Cell Research Center and its Advanced Power and Energy Program are focusing research, education, beta testing, and outreach on high-efficiency, environmentally preferred energy conversion and power generation technology with fuel cell and gas turbine systems as the principal targets. Current research projects address ultra-high efficiency and ultra-low emissions high-temperature fuel cell systems, integrated hybrid fuel cell gas turbine systems, renewable power intermittency and integration, battery electric and plug-in hybrid electric vehicle evaluation and infrastructure development, advanced fuel cell and gas turbine dynamic operations, hydrogen and electricity infrastructure development, and power electronics and energy conversion devices for the smart grid. Prior to joining UCI, Brouwer was on the faculty at the University of Utah, a senior engineer at Reaction Engineering International, and a staff scientist at Sandia National Laboratories.

Brouwer's key research areas include science and engineering of energy conversion with coupled mass, energy and momentum conservation, chemical and electrochemical reaction, and heat transfer; steady-state and dynamic modeling of fundamental processes that govern energy conversion devices such as fuel cells, electrolyzers, and gas turbine engines; solid-state ionics and electrochemistry; fuel processing; synthesis and experimental investigation of novel fuel cell materials sets; analyses of integrated energy systems comprising fuel cells, photovoltaics, fuel processing, gas turbines, and wind turbines; experimental analyses and model validation; renewable energy; and life-cycle analyses of energy conversion technologies.

Dr. Brouwer holds a Ph.D. in mechanical engineering from the Massachusetts Institute of Technology and a M.S. and B.S. in mechanical engineering from UCI.

Minking K. Chyu, Ph.D.

Dr. Chyu is Associate Dean for International Initiatives in the Swanson School of Engineering at the University of Pittsburgh. His research interests include thermo-fluid issues related to power and propulsion systems, 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 a DOE-NETL Faculty Fellow, associate fellow of the American Society of Aeronautics and Astronautics, ASME Engineer of the Year Award, and DOE Advanced-Turbine-System Faculty Fellow. Dr. Chyu is also a fellow of ASME, a member of the Heat Transfer Technical Committee in Gas Turbines (K-14), and an advisory board member of the Center for Advanced Energy and Environment, National Tsing Hua University in Taiwan. He served as Associate Editor of the ASME *Journal on Heat Transfer*, worked on National Science Foundation (NSF) Propane Review Panels, and is a member of the Scientific Council for the International Centre for Heat and Mass Transfer. Dr. Chyu has authored over 70 publications and more than 100 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 30 grants, and has graduated 12 Ph.D. and 20 M.S. students.

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.

Wayne Huebner, Ph.D.

Dr. Huebner is a professor and chair of the Ceramic Engineering Department at the Missouri University of Science and Technology, where he is also a senior investigator with the Materials Research Center. Prior to that, Huebner was an assistant professor of Ceramic Science and Engineering at the Pennsylvania State University.

Dr. Huebner’s research interests include the preparation, characterization, and theoretical understanding of electronic ceramics, in particular ferroelectrics, piezoelectrics, varistors, thermistors, superionic conductors, solid oxide electrolytes, fuel cells, and oxygen separation membranes.

Huebner was recognized by the American Ceramic Society in 1995 with the Karl Schwartzwalder Professional Achievement in Ceramic Engineering Award, the Missouri Science & Technology Outstanding Teaching Award, the Dr. Edward F. Tuck Excellence Award, and the McDonnell Douglas Faculty Excellence Award. He holds a patent for Method of Manufacture of Multiple-Element Piezoelectric Transducer and has published numerous articles in peer-reviewed academic journals.

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