FY18 SOLID OXIDE FUEL CELLS (SOFC) PROGRAM
PEER REVIEW
OVERVIEW REPORT

May 11, 2018

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

DISCLAIMER

TABLE OF CONTENTS

EXECUTIVE SUMMARY

KeyLogic (National Energy Technology Laboratory [NETL] site-support contractor) convened an independent panel of four leading academic and industry experts* on February 20, 2018, to conduct a one-day peer review of NETL's Solid Oxide Fuel Cells (SOFC) Program. In consultation with the U.S. Department of Energy (DOE) representatives who selected the program for review, KeyLogic procured this independent peer review panel, facilitated the peer review meeting, and prepared this report to summarize the results.

The panel was chartered to assess the SOFC Program's relevance; its mission, goals, and objectives; the technical approach to achieving said mission, goals, and objectives; the technology development timeline; the program's project portfolio; program management approach; resources; and its future plans. Prior to the peer review, the panel was provided a list of evaluation criteria for consideration, developed by KeyLogic and the Office of Fossil Energy (FE), to guide their assessment.

The meeting comprised a full day. The morning session was dedicated to a presentation by the SOFC Program Technology Manager (TM), Dr. Shailesh Vora; the afternoon session consisted of an intra-panel discussion (the TM, NETL, FE, and KeyLogic personnel were present as observers and not active participants), followed by a wrap-up session where the panelists summarized their findings and prioritized their recommendations.

The tenor of the meeting was positive and supportive of the program's overall strategy. The panel concluded the program is well aligned with relevant Congressional appropriations language and its goals and objectives are well-defined. The panelists discussed at length the program's strategy to test progressively larger stack and systems and unanimously endorsed the approach to achieve its mission, goals, and objectives. The panelists suggested the program should consider funding multiple 200 kWe-class prototype field tests, as well as MWe-class pilot-scale tests, to better understand and resolve system integration issues and accrue cost reductions through volume manufacturing.

The panelists concurred that:

- The short-term focus on natural gas-fueled distributed generation is a sound strategy.
- The technical goals are well-defined.
- Increased research and development (R&D) to determine and address the root cause(s) of higher than desirable voltage degradation in system tests is warranted.
- The allocation of funding within the entire program should be re-evaluated and modified to emphasize programs that support the near-term successful development of the leading MWe-class SOFC technologies, and deemphasize programs that have little or no relevance to the near-term demonstration of MWe-class SOFC systems.

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* Please see "Appendix D: Peer Review Panel Members" for detailed panel member biographies.

SOLID OXIDE FUEL CELLS PROGRAM

The mission of the Solid Oxide Fuel Cells (SOFC) Program is to enable the generation of efficient, low-cost electricity for: (a) 2nd Generation natural gas-fueled distributed generation (DG) systems and modular coal-fueled systems, and (b) Transformational coal or natural gas-fueled, utility-scale systems with carbon capture and storage (CCS). The program supports the overarching goals of the Clean Coal and Carbon Management Research Program (CCCMRP) through research and development (R&D) that addresses the technical and economic barriers to commercial viability, and the development and deployment of SOFC power systems that validates those solutions.

SOFCs offer the highest conversion efficiency of chemical energy to electrical energy of any energy conversion technology, producing more electricity per unit of fuel than any heat engine. This thermodynamic advantage, which also translates into proportionally lower emissions, along with the technology's intrinsic carbon capture capability, makes SOFCs one of the most promising technologies within the U.S. Department of Energy (DOE) Office of Fossil Energy (FE) portfolio.

The targeted technology developments and performance objectives for the SOFC Program apply to units fueled by both natural gas and coal-derived syngas, resulting in a system that can utilize existing natural gas distribution infrastructure or that can be readily integrated with a coal gasification system. The performance and reliability enhancements and cost reduction pursued by the SOFC Program for coal-fueled, utility-scale generation are aligned with the near-term DG goals of industry—without compromising the goals of the coal-based program.

The CCCMRP conducts and supports long-term, high-risk R&D to significantly reduce fossil fuel power plant emissions (including carbon dioxide [CO_2]) and to substantially improve efficiency, leading to viable, near-zero emissions from fossil fuel energy systems. It pursues two categories of technologies: 2nd Generation and Transformational. The 2nd Generation technologies are those currently in R&D, scheduled to become available for large-scale testing around 2020, and available for commercial deployment in the 2025 timeframe. Transformational technologies are emerging technologies in early stages of development. They offer the potential for game-changing improvements in cost and performance forecast to be available for large-scale testing around 2030, and available for commercial deployment in the 2035 timeframe (1st Generation technologies are those currently being demonstrated or are commercially available). The 2nd Generation (near-term) SOFC Program goal is the development of a natural gas-fueled MWe-class SOFC power system for DG application. The Transformational (long-term) goal is to complete the development of a highly efficient utility-scale SOFC system that can utilize coal-derived syngas (and also natural gas) as fuel with essentially the same fuel cell module. Deployment of SOFC power systems will significantly contribute toward achieving the CCCMRP Transformational goal of developing a coal-fueled power plant with carbon capture that has a cost of electricity 30% lower than a supercritical pulverized coal power plant with carbon capture.

OVERVIEW OF THE PEER REVIEW PROCESS

DOE and the National Energy Technology Laboratory (NETL) are fully committed to improving the quality and results of their research programs. Peer reviews improve the overall quality of the technical aspects of R&D activities, as well as overall project-related activities, such as utilization of resources, project and financial management, and commercialization.

KeyLogic (NETL site-support contractor) convened an independent panel of leading academic and industry experts on February 20, 2018, to conduct a one-day peer review of NETL's SOFC Program[†]. Throughout the peer review meeting, these recognized technical experts offered comments and recommendations regarding the program's relevance, technology development timeline, program impacts, and program outreach activities. In consultation with the DOE representatives who selected the program for review, KeyLogic procured this independent peer review panel, facilitated the peer review meeting, and prepared this report to summarize the results.

Pre-Meeting Preparation

Before the peer review, the SOFC Program official provided the review panel with a documentation package consisting of a program overview and description; accomplishments, status, and roadmap; appropriation language; link to the SOFC Program information on the NETL website; NETL Technology Readiness Level (TRL) definitions; and an SOFC Program presentation. The review panel also received a program-based list of evaluation criteria that were drafted in consultation with DOE. The review panel received these materials prior to the peer review meeting, which enabled the panel members to fully prepare for the meeting with the necessary background information to thoroughly evaluate the program.

To increase the efficiency of the peer review meeting, multiple pre-meeting orientation teleconference calls were held with the review panel, NETL Peer Review Coordinator, and KeyLogic staff to review the peer review process and procedures, evaluation criteria, and program documentation.

Peer Review Meeting Proceedings

At the meeting, the SOFC Program official (Technology Manager [TM]; Dr. Shailesh Vora) gave a presentation describing the program. The presentation was followed by a question-and-answer session with the panel and a panel discussion and evaluation. The review panel discussed the program and offered comments/observations and prioritized recommendations in accordance with the Peer Review Evaluation Criteria.

[†] Please see "Appendix D: Peer Review Panel Members" for detailed panel member biographies.

APPENDIX A: PEER REVIEW EVALUATION CRITERIA

SOFC Program Peer Review Evaluation Criteria

Topics for Consideration

1. **Program Relevance**
   - Is the program in alignment with appropriation language?
   - Is the program mission clearly articulated?
   - Are the technical program goals and objectives appropriate for its mission?
   - Have the research gaps been clearly defined?
   - Is the program's approach to the research gaps achievable?
   - Are there parts of the program that should be concluded?
2. **Technology Development Timeline**
   - Technology Timeline
     - i. Is the technical approach appropriately and reasonably paced to achieve goals?
     - ii. Is the technology foundation (i.e., current state-of-the-art, past accomplishments) strong enough to move forward with objectives?
     - iii. Is the short-term focus on natural gas with a long-term transition to focus on coal appropriate?
   - Project Portfolio
     - i. Are the number of projects and level of TRLs properly balanced?
     - ii. Are the types of program participants (e.g., national labs, academia, and industry) appropriate and balanced?
   - Program Management
     - i. Are there research areas that need added, modified, or ended?
     - ii. Is the program effective in soliciting industry feedback to guide R&D teams?
     - iii. Is funding appropriately allocated across development areas?
     - iv. Is adequate attention being directed toward technology gaps?
     - v. Is the technology transfer approach through the development process appropriate?
     - vi. Is there collaboration among participants?
     - vii. Is there potential for improvements to collaboration?
     - viii. Is there adequate balance between R&D and demonstrations?
3. **Program Impacts**
   - Are the current and expected future economic benefits reasonable and competitive?
   - From your perspective, what are the qualitative program impacts on the public?
   - Should the Government continue to fund this program? For what reasons, and in what direction?
4. **Program Outreach**
   - Are the program's updates and achievements well publicized?
   - Is there appropriate collaboration with other Federal agencies (e.g., Advanced Research Projects Agency-Energy [ARPA-E], EERE), national laboratories, and the U.S. Department of Defense (DoD)?
5. **Technology Gaps**
   - Is the current single-cell stack and system decay rate achievable in the defined time?
   - Does the cathode-supported tubular design have better long-term stability?
   - Does cathode support address differences between previous/current; is it an improvement?
   - Are technology gaps for commercialization being adequately addressed to compete with other conventional power systems?

APPENDIX B: NETL TECHNOLOGY READINESS LEVELS

NETL Technology Readiness Levels (TRLs)

NETL supports a wide range of research, development, and demonstration (RD&D) projects, from small, short-duration materials development and property characterization projects up to large-scale power plant demonstrations. The nature and complexity of the technology under development will have implications for the application of the Technology Readiness concept, particularly with respect to supporting systems analysis requirements.

Accompanying the TRL definitions and descriptions provided in the table below are Systems Analysis Best Practices. These Best Practices serve as a critical resource to guide the identification of performance attributes and to establish corresponding performance requirements for a given technology which are, in turn, tied to the intended commercial application and higher-level goals (e.g., program goals). A systems analysis is carried out to estimate the performance and cost of the technology based on the information (e.g., experimental data) that is expected to be available at a particular TRL. The results, when compared with conventional technology, are used to inform the next stage of development and provide specific experimental and analysis success criteria (the performance requirements). The performance requirements that may be appropriately tested at a particular TRL must be substantially met, thereby supporting the feasibility of commercial success/goal achievement, prior to proceeding to the subsequent TRL. Note that, as with the TRL descriptions, these Systems Analysis Best Practices are “gate-in”; that is, prerequisites to achieving the associated TRL.

TRL	Definition	Description	Systems Analysis Best Practices
1	**Basic principles observed and reported**	Core Technology Identified. Scientific research and/or principles exist and have been assessed. Translation into a new idea, concept, and/or application has begun.	Assessment: Perform an assessment of the core technology resulting in (qualitative) projected benefits of the technology, a summary of necessary R&D needed to develop it into the actual technology, and principles that support of the viability of the technology to achieve the projected benefits.
2	**Technology concept and/or application formulated**	Invention Initiated. Analysis has been conducted on the core technology for practical use. Detailed analysis to support the assumptions has been initiated. Initial performance attributes have been established.	White Paper: A white paper describing the intended commercial application, the anticipated environment the actual technology will operate in, and the results from the initiation of a detailed analysis (that will at least qualitatively justify expenditure of resources versus the expected benefits and identify initial performance attributes).
3	**Analytical and experimental critical function and/or characteristic proof-of-concept validated**	Proof-of-Concept Validated. Performance requirements that can be tested in the laboratory environment have been analytically and physically validated. The core technology should not fundamentally change beyond this point. Performance attributes have been updated and initial performance requirements have been established.	Performance Model and Initial Cost Assessment: This performance model is a basic model of the technology concept, incorporating relevant process boundary conditions, that provides insight into critical performance attributes and serves to establish initial performance requirements. These may be empirically or theoretically based models represented in Excel or other suitable platforms. In addition, an initial assessment and determination of performance requirements related to cost is completed.
4	**Basic technology components integrated and validated in a laboratory environment**	Technology Validated in a Laboratory Environment. The basic technology components have been integrated to the extent practical (a relatively low-fidelity integration) to establish that key pieces will work together, and validated in a laboratory environment. Performance attributes and requirements have been updated.	System Simulation and Economic Analysis: These models incorporate a performance model of the technology (may be a simple model as developed for TRL 3, or something more detailed – either should be validated against empirical data gathered in the laboratory) into a model of the intended commercial system (e.g., power plant). In addition, an economic analysis (e.g., cost of electricity) of the technology is performed, assessing the impact of capital costs, operating and maintenance costs, and life on the impact of the technology and its contributions to the viability of the overall system in a commercial environment. These analyses serve to assess the relative impact of known performance attributes (through sensitivity analyses) and refine performance requirements in the context of established higher-level technical and economic goals (e.g., programmatic or DOE R&D goals). These models are typically created in process simulation software (e.g., ASPEN Plus) or other suitable platforms. DOE maintains guidance on the execution of techno-economic analyses[1].

TRL	Definition	Description	Systems Analysis Best Practices
5	**Basic technology components integrated and validated in a relevant environment**	Technology Validated in a Relevant Environment. Basic technology component configurations have been validated in a relevant environment. Component integration is similar to the final application in many respects. Data sufficient to support planning and design of the next TRL test phase have been obtained. Performance attributes and requirements have been updated.	System Simulation and Economic Analysis Refinement: A more detailed process model for the technology, validated against empirical data gathered in the laboratory, will be developed and incorporated into system simulations. This provides greater fidelity in the performance and cost estimation for the technology, facilitating updates to performance attributes and requirements (including updates to the economic analysis). This also allows greater evaluation of other process synergy claims (e.g., state-of-the-art technology is improved by the use of the new technology). Cost estimation should be either vendor-based or bottom-up costing approaches for novel equipment.
6	**Prototype validated in a relevant environment**	Prototype Validated in Relevant Environment. A prototype has been validated in a relevant environment. Component integration is similar to the final application in most respects and input and output parameters resemble the target commercial application to the extent practical. Data sufficient to support planning and design of the next TRL test phase have been obtained. Performance attributes and requirements have been updated.	System Simulation and Economic Analysis Refinement: Performance and cost models are refined based upon relevant environment laboratory results, leading to updated performance attributes and requirements. Preliminary steady-state and dynamic (if appropriate for the technology) modeling of all critical process parameters (i.e., upper and lower operating limits) of the system prototype is completed. Cost estimation should be either vendor-based or bottom-up costing approaches for novel equipment. Key process equipment should be specified to the extent that allows for bottom-up estimating to support a feasibility study of the integrated system.
7	**System prototype validated in an operational system**	System Prototype Validated in Operational Environment. A high-fidelity prototype, which addresses all scaling issues practical at pre-demonstration scale, has been built and tested in an operational environment. All necessary development work has been completed to support Actual Technology testing. Performance attributes and requirements have been updated.	System Simulation and Economic Analysis Refinement: Performance and cost models are refined based upon relevant environment and system prototype R&D results. The refined process, system and cost models are used to project updated system performance and cost to determine if the technology has the potential to meet the project goals. Performance attributes and requirements are updated as necessary. Steady-state and dynamic modeling all critical process parameters of the system prototype covering the anticipated full operation envelope (i.e., upper and lower operating limits) is completed. Cost models should be based on vendor quotes and traditional equipment estimates should be minimal.

TRL	Definition	Description	Systems Analysis Best Practices
8	**Actual technology successfully commissioned in an operational system**	Actual Technology Commissioned. The actual technology has been successfully commissioned for its target commercial application, at full commercial scale. In almost all cases, this TRL represents the end of true system development.	System Simulation and Economic Analysis Validation: The technology/system process models are validated by operational data from the demonstration. Economic models are updated accordingly.
9	**Actual technology operated over the full range of expected operational conditions**	Commercially Operated. The actual technology has been successfully operated long-term and has been demonstrated in an operational system, including (as applicable) shutdowns, startups, system upsets, weather ranges, and turndown conditions. Technology risk has been reduced so that it is similar to the risk of a commercial technology if used in another identical plant.	Commercial Use: Models are used for commercial scaling parameters.

[1] *Performing a Techno-economic Analysis for Power Generation Plants, DOE/NETL-2015/1726, July 2015.*

Glossary of Terms

Actual Technology: The final product of technology development that is of sufficient size, performance, and reliability—ready for use at the target commercial application. The technology is at Technology Readiness Levels (TRLs) 8–9.

Basic Technological Components Integrated: A test apparatus that ranges from (1) the largest, most integrated and/or most realistic technology model that can reasonably be tested in a laboratory environment, to (2) the lowest-cost technology model that can be used to obtain useful data in a relevant environment.

Commissioning/Commission: The actual system has become operational at target commercial conditions and is ready for commercial operations.

Concept and/or Application: The initial idea for a new technology or a new application for an existing technology. The technology is at TRLs 1–3.

Core Technology: The idea, new concept, and/or new application that started the research and development (R&D) effort. Examples include: (1) a new membrane material, sorbent, or solvent; (2) new software code; (3) a new turbine component; (4) the use of a commercial sensor technology in more durable housing; or (5) the use of a commercial enhanced oil recovery technology to store CO_2. Typically this is a project's intellectual property.

Economic Analysis: The process of estimating and assigning costs to equipment, subsystems, and systems, corresponding to models of and specifications for the commercial embodiment of the technology. Such analyses include the estimation of capital costs, as well as operating and maintenance costs. Component service life and corresponding replacement costs are often a crucial aspect of these analyses. See *Performing a Techno-economic Analysis for Power Generation Plants, DOE/NETL-2015/1726, July 2015,* for further guidance.

Fidelity: The extent to which a technology and its operating environment/conditions resemble that of the target commercial application.

Integrated: The functional state of a system resulting from the process of bringing together one or more technologies or subsystems and ensuring that each function together as a system.

Laboratory Environment: An environment isolated from the commercial environment in which lower-cost testing is performed to obtain high-quality, fundamental data at earlier TRLs. For software development, this is a small-scale, simplified domain for a software mockup.

Operational System: The environment in which the technology will be tested as part of the target commercial application.

Performance Attributes: All aspects of the technology (e.g., flux, selectivity, life, durability, cost, etc.) that must be tested or otherwise evaluated to ensure that the technology will function in the target commercial application, including all needed support systems. Systems analysis may assist in the identification of relevant performance attributes. It is likely that the performance attributes list will increase as the technology matures. Performance attributes must be updated as new information is received and formally reviewed at each TRL transition.

Performance Requirements: Criteria that must be met for each performance attribute before the actual system can be used at its target commercial application. These will be determined—typically via systems analysis—in consideration of program goals, requirements for market competitiveness for the target commercial application, etc. Performance requirements may change over time, and it is unlikely that all of them will be known at a low TRL.

Program: The funding program. The program goals will be used to judge project value and, in concert with systems analysis, will support acceptable performance requirements for the project. The funding program will also determine whether the system will be tested under one or several sets of target commercial applications.

Project: The funding mechanism for technology development, which often spans only part of the technology development arc. Some projects may contain aspects that lack dependence; these may have different TRL scores, but this must be fully justified.

Proof-of-Concept: Reasonable conclusions drawn through the use of low-fidelity experimentation and analysis to validate that the new idea—and resulting new component and/or application—has the potential to lead to the creation of an actual system.

Prototype: A test apparatus necessary to thoroughly test the technology, integrated and realistic as much as practical, in the applicable TRL test environment.

Relevant Environment: More realistic than a laboratory environment, but less costly to create and maintain than an operational environment. This is a relatively flexible term that must be consistently defined by each program (e.g., in software development, this would be "beta testing").

Systems Analysis: The analytic process used to evaluate the behavior and performance of processes, equipment, subsystems, and systems. Such analyses serve to characterize the relationships between independent (e.g., design parameters and configurations, material properties, etc.) and dependent variables (e.g., thermodynamic state points, output, etc.) through the creation of models representative of the envisioned process, equipment, subsystem, or system. These analyses are used to determine the variables important to desired function in the target commercial application (i.e., performance attributes) and the associated targets that must be achieved through R&D and testing to realize program and/or commercial goals (i.e., performance requirements). Models and simulations may use a variety of tools, such as Excel, Aspen Plus, Aspen Plus Dynamics, etc., depending upon the scope of the development effort and the stage of development. See *Performing a Techno-economic Analysis for Power Generation Plants, DOE/NETL-2015/1726, July 2015,* for further guidance.

Systems Analysis Best Practices: These best practices serve as a guide for the level of systems and economic analysis rigor and level of effort appropriate for each TRL. The scope of the project—the subject and nature the technology under development—must be considered when applying these best practices. For example, the analytical effort associated with the development of a thermal barrier coating is quite different than that appropriate to the development of a post-combustion CO_2 capture system.

Target Commercial Application: This refers to one specific use for the actual system, at full commercial scale, which supports the goals of the funding program. A project may include more than one set of target commercial applications. Examples include:

1. Technologies that reduce the cost of gasification may be useful for both liquid fuels and power production.
2. Technologies that may be useful to monitor CO_2 storage in more than one type of storage site.

Technology: The idea, new concept, and/or new application that started the R&D effort, plus other R&D work that must be done for the project's core technology to translate into an actual system.

Technology Aspects: Different R&D efforts, both within and external to any given project. Examples include material development, process development, process simulation, contaminant removal/control, and thermal management.

Validated: The proving of all known performance requirements that can reasonably be tested using the test apparatus of the applicable TRL.

APPENDIX C: MEETING AGENDA

Solid Oxide Fuel Cells Peer Review
February 20, 2018
NETL-Pittsburgh Building 922 Room 106A

Tuesday, February 20, 2018

8:00 a.m.	Arrive at the NETL-Pittsburgh Entrance Gate for Security Check
8:15 – 8:30 a.m.	Visitors escorted to NETL-Pittsburgh Building 922 Room 106A
8:30 – 9:00 a.m.	Peer Review Panel Kickoff Session - Welcome, Introductions, Peer Review Process, and Meeting Logistics
9:00 – 10:30 a.m.	National Energy Technology Laboratory's Solid Oxide Fuel Cells Program *Shailesh Vora* – National Energy Technology Laboratory
10:30 – 10:45 a.m.	BREAK
10:45 – 12:15 p.m.	Question and Answer Session
12:15 – 12:45 p.m.	Lunch (onsite cafeteria; cash only, orders will be placed during 10:30 a.m. BREAK)
12:45 – 1:45 p.m.	Peer Review Panel Discussion *DOE HQ/NETL and KeyLogic peer review support staff attend as observers.*
1:45 – 2:00 p.m.	BREAK
2:00 – 2:30 p.m.	Peer Review Panel Discussion (continued) *DOE HQ/NETL and KeyLogic peer review support staff attend as observers.*
2:30 – 3:00 p.m.	Peer Review Panel Wrap-Up Session
3:00 p.m.	Adjourn

APPENDIX D: PEER REVIEW PANEL MEMBERS

Solid Oxide Fuel Cells Peer Review
February 20, 2018
NETL-Pittsburgh Building 922 Room 106A

Jack Brouwer, Ph.D.

Dr. Jack Brouwer is an 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, Dr. 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.

Dr. 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 an M.S. and B.S. in mechanical engineering from UCI. Dr. Brouwer previously served on the Fiscal Year (FY) 2016 and FY 2017 SOFC Peer Review Panels.

Raymond George

Raymond George has more than 40 years of industry experience in the nuclear power and SOFC power generation fields. His experience at Westinghouse Commercial Nuclear Power included managing the Nuclear Fuel Division Advanced Pressurized Water Reactor Development Program and plant marketing. He also served as Engineering Manager of the SOFC Development Program at the Westinghouse R&D Center. Mr. George served as manager of both Engineering and Manufacturing for SOFC Power Generation (sold to Siemens in 1998) and Chief Technology Officer of Stationary Fuel Cells for Siemens Power Generation. Following his time as Chief Technology Officer, Mr. George offered consulting support to Siemens. Mr. George also offered consulting support to Israeli Company on solid oxide electrolysis.

Mr. George studied nuclear engineering at Carnegie Mellon University and holds an M.E. and B.S. in nuclear engineering from Rensselaer Polytechnic Institute. Mr. George previously served on the FY 2017 SOFC Peer Review Panel.

Ravi Prasad, Ph.D.

Dr. Ravi Prasad of Helios-NRG, LLC, and formerly a corporate fellow of Praxair, Inc., holds 60 U.S. patents and has broad industrial experience in developing and commercializing new technologies, launching technology programs ($2–$50 million), supporting business development, building cross-functional teams, and setting up joint development alliances. Dr. Prasad was a founding member of an alliance involving Praxair, British Petroleum, Amoco, Phillips Petroleum, Statoil, and Sasol to develop ceramic membrane synthesis gas (syngas) technology for gas-to-liquid processes.

Dr. Prasad established and led programs for ceramic membrane oxygen technology; codeveloped proposals to secure major DOE programs worth $35 million in syngas and $20 million in oxygen; identified novel, solid-state oxygen generation technology; and conceived and implemented a coherent corporate strategy in nanotechnology. He has championed many initiatives in India, including small, onsite hydrogen plants, small gasifiers, and aerospace business opportunities, and developed implementation plans resulting in a new R&D center in Shanghai. Dr. Prasad is the director and a board member of the National Hydrogen Association, a member of the steering committee for Chemical Industry Vision 2020, and has been a recipient for Chairman's and Corporate Fellows' awards for technology leadership. He has authored or coauthored more than 30 publications, is coauthor of a book on membrane gas separation, has presented at more than 20 conferences, and delivered invited lectures.

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. Dr. Prasad has previously served on the following peer review panels: FY 2015 Carbon Capture (Panel Chair), FY 2014 SOFC (Panel Chair), FY 2014 Advanced Combustion Systems (Panel Chair), FY 2013 Carbon Storage (Panel Co-Chair), FY 2013 Carbon Capture, FY 2012 Advanced Energy Systems (Panel Chair), FY 2011 Advanced Fuels, FY 2010 Advanced Integrated Gasification Combined Cycle, and FY 2010 Carbon Sequestration.

Subhash Singhal, Ph.D.

Dr. Singhal is a Battelle fellow and fuel cell director at DOE's Pacific Northwest National Laboratory (PNNL), where he provides senior technical, managerial, and commercialization leadership to PNNL's Fuel Cell Program. A recognized expert in SOFCs, Dr. Singhal also serves as an adjunct professor in the Department of Materials Science and Engineering at the University of Utah. Prior to joining PNNL in 2000, Dr. Singhal led fuel cell development at Siemens Power Generation (formerly Westinghouse Electric Corporation) for nearly 30 years, conducting and/or managing major research, development, and demonstration programs in the field of advanced materials for various energy conversion systems, including steam and gas turbines, coal gasification, and fuel cells. While at Siemens, Dr. Singhal served as the manager of Fuel Cell Technology from 1984 to 2000, during which he was responsible for the development of high-temperature SOFCs for stationary power generation and led an internationally recognized group that brought SOFC technology from a few-watt laboratory curiosity to a fully integrated 200-kW size power generation system.

A member of the National Academy of Engineering and a fellow of four professional societies (American Association for the Advancement of Science, American Ceramic Society, ASM International, and Electrochemical Society), Dr. Singhal has a bachelor's degree in metallurgy from the Indian Institute of Science; a bachelor's degree in physics, chemistry, and mathematics from Agra University, India; an MBA from the University of Pittsburgh; and a Ph.D. in materials science engineering from the University of Pennsylvania. Dr. Singhal has authored more than 75 scientific publications; edited 13 books; received 13 patents; and given more than 240 plenary, keynote, and other invited presentations worldwide.