OVERVIEW REPORT

DOE/NETL Clean Coal Research Program
Hydrogen Turbines Program
FY2014 Peer Review Meeting

Pittsburgh, Pennsylvania
April 14-15, 2014

ASM INTERNATIONAL

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OVERVIEW REPORT
CLEAN COAL RESEARCH PROGRAM
HYDROGEN TURBINES PROGRAM
FY2014 PEER REVIEW MEETING

Pittsburgh, Pennsylvania
April 14–15, 2014

NETL Business Management Specialist and Peer Review Coordinator
Eric Bell
(412) 386-5802

Meeting Host Organization
Leonardo Technologies, Inc.
David Wildman
(412) 386-4791

Review Panel
ASM International
Klaus Brun, Chair, Peer Review Panel
Stan Theobald, Senior Director, Business Development
ASM International
(440) 338-5151 ext. 5502

Meeting Facilitator and Final Report
Ross Brindle, Nexight Group
(240) 667-7636

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The work performed on this task/subtask was completed under Leonardo Technologies, Inc. (LTI), Prime Contract DE-FE0004002 (Subtask 300.02.09) for DOE-NETL.

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INTRODUCTION AND BACKGROUND

Hydrogen Turbines Program Mission and Goals

The U.S. Department of Energy (DOE) is committed to using coal in ways that are cleaner and more efficient and that reduce carbon dioxide (CO_2) emissions. Advancing hydrogen turbine performance in integrated gasification combined cycle (IGCC) power plants offers the most significant near-term performance benefit for reducing emissions and cost while increasing efficiency. The ultimate goal of the Hydrogen Turbines Program is to facilitate the development of advanced components and technology for turbines that provide tangible benefits to the public: lower cost of electricity (COE), reduced emissions of criteria pollutants, and carbon capture options.

The Hydrogen Turbines Program is organized into five key areas: Hydrogen Turbines, Oxy-Fuel Turbines, the University Turbine Systems Research (UTSR) program, Advanced Research, and Small Business Innovation Research (SBIR) projects. The program is augmented by a portfolio of American Recovery and Reinvestment Act (ARRA) funding for advancing industrial application of carbon capture and storage (CCS), and the National Energy Technology Laboratory (NETL) Regional University Alliance (RUA) collaboration that utilizes the extensive expertise and facilities available at NETL and five nationally recognized regional universities.

The Hydrogen Turbines Program has identified goals to deliver hydrogen-fueled combined cycle power modules for the 2020 time horizon that demonstrate the following achievements:

- Efficiency
  - -2–3 percentage points improvement in combined cycle efficiency (2010) and 3–5 percentage points by 2015 above the baseline
  - -4 percentage point improvement in overall IGCC plant efficiency with CCS by 2015
- Cost Reduction
  - -20–30 percent reduction in combined cycle capital costs
  - -25 percent reduction in total overnight capital cost for IGCC with CCS
  - -25 percent reduction in COE for IGCC with CCS
- Emissions
  - -Turbine nitrogen oxide (NOx) emissions in single digits (at 15 percent oxygen [O_2])
  - -IGCC plant optimized for firing temperature with 2 parts per million (ppm) NOx at the stack (includes selective catalytic reduction)

The DOE investment in advanced turbine technology promotes positive outcomes in U.S. technology leadership, global competitiveness, a cleaner environment, and domestic job growth. Scientific and engineering challenges are being met through cost-shared research and development partnerships between industry, academia, and the Government. The Hydrogen Turbines Program strives to meet these challenges through research and development.

Resolving the scientific and engineering design challenges using the approaches outlined above will allow hydrogen-fueled turbines to be used in IGCC power systems with carbon capture and storage (CCS).

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 Hydrogen Turbines 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 14–15, to conduct a two-day peer review of selected Hydrogen Turbines Program research projects supported by NETL.

Overview of Office of Fossil Energy Hydrogen Turbines Program Research Funding

The total funding of the six projects reviewed, over the duration of the projects, is $138,081,629. The six projects that were the subject of this peer review are summarized in Table 1 and in the Reviewer Comments section of this report.

TABLE 1. HYDROGEN TURBINE PROJECTS REVIEWED

Reference Number	Project No.	Title	Lead Organization	Principal Investigator	Total Funding		Project Duration	
					DOE	Cost Share	From	To
1	N/A	Office of Program Performance & Benefits (OPPB) Support to the Hydrogen Turbines Program - Overview	National Energy Technology Laboratory – Office of Program Performance & Benefits	N/A	N/A	N/A	N/A	N/A
1	OPPB/PD-1	Assessment of Supercritical CO_2 Cycles	National Energy Technology Laboratory - Office of Program Performance & Benefits (NETL OPPB)	Walter Shelton	$330,000	$0	08/08/2012	11/14/2014
2	FE0011822	Effects of Exhaust Gas Recirculation (EGR) on Turbulent Combustion and Emissions in Advanced Gas Turbine Combustors with High-Hydrogen-Content (HHC) Fuels	Purdue University	Robert Lucht	$500,000	$150,355	10/01/2013	09/30/2016
3	FE0011875	Thermally Effective and Efficient Cooling Technologies for Advanced Gas Turbines	University of North Dakota	Forrest Ames	$499.996	$124,998	10/01/2013	09/30/2016
4	FWP-2012.03.02 Tasks 2, 3 and 4	Turbine Thermal Management: Near Surface Embedded Micro-channel (NSEMC) Cooling	National Energy Technology Laboratory - Office of Research & Development (NETL ORD)	Mary Anne Alvin	$813,256	$0	10/01/2013	09/30/2014
5	FWP-FEAA112	Materials Issues in Supercritical Carbon Dioxide	Oak Ridge National Laboratory (ORNL)	Bruce A. Pint	$450,000	$0	10/01/2012	09/30/2014
6	FC26-05NT42644	Recovery Act: Advanced Hydrogen Turbine Development	Siemens Energy, Inc.	John Marra	$82,121,591	$53,091,433	10/01/2005	06/30/2015
				TOTALS	**$84,714,843**	**$53,366,786**	**--**	**--**

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 Hydrogen Turbines Program. The peer review of selected projects within the Hydrogen Turbines Program was designed to comply with requirements from the Office of Management and Budget.

On April 14–15, 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 Hydrogen Turbines 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 Hydrogen Turbines 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 45-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, project team members, 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 Supercritical CO_2 Cycles; 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 six projects evaluated at the FY2014 Hydrogen Turbines Peer Review.

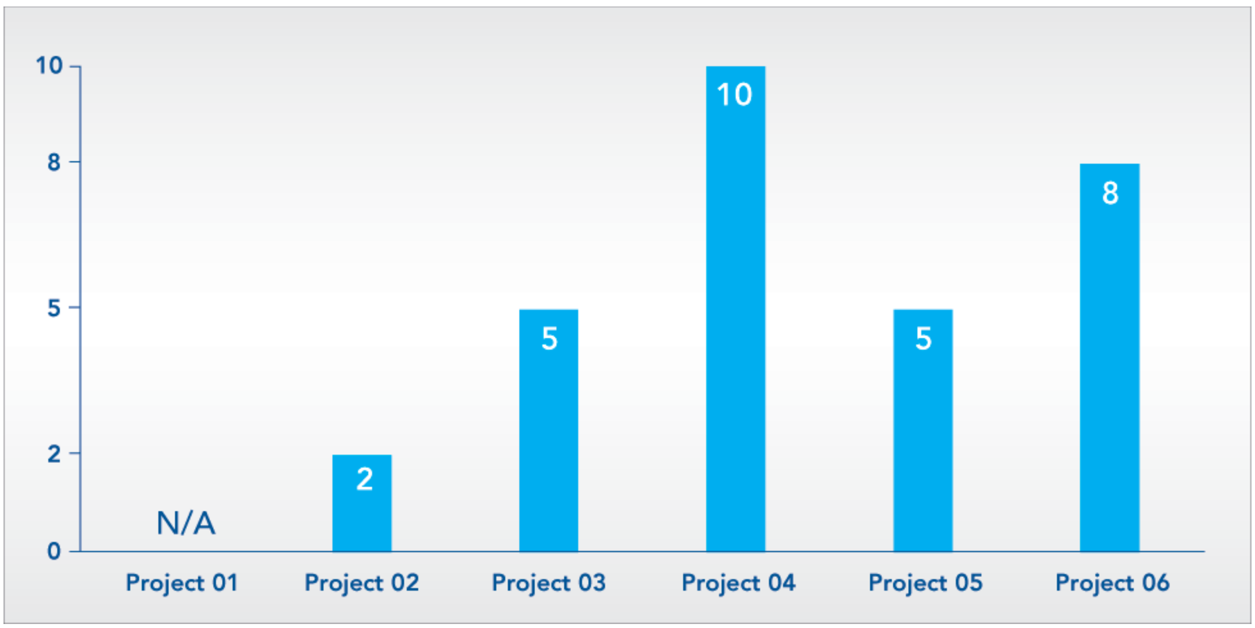
Overview of Project Evaluation Scores

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 1.

FIGURE 1. EVALUATION SCORES, BY PROJECT



General Project Strengths

The panel was impressed by the high-quality of several of the hydrogen turbine projects they reviewed from DOE's Clean Coal Research Program. They indicated that the projects presented have ambitious goals and significant potential to advance hydrogen turbine technology toward applications using coal-derived synthesis gas, hydrogen, and other fossil fuels for power generation. These six projects are representative of a well-balanced portfolio of fundamental science, national laboratory research, and large-scale industry projects. Based on the progress made to date by the projects reviewed, the panel was optimistic about the potential for important further progress toward achieving DOE's challenging goals for increasing efficiency while reducing the cost and emissions of hydrogen-fueled combined cycle power systems with and without carbon capture. Finally, panel members noted that the program is successfully connecting university and industry-led projects, accelerating the impact of university-led research on commercially relevant systems.

Figure 1 displays the comprehensive project evaluation scores for each project. Panel members noted that the success of projects was largely attributed to diligent communication with stakeholders, multidisciplinary partnerships with partner organizations, and high-level assessment of the barriers to successful commercialization of hydrogen turbine technologies.

The highest-rated project was project 04, “Turbine Thermal Management: Near Surface Embedded Micro-Channel (NSEMC) Cooling,” conducted by NETL, Ames Laboratory, and the University of Pittsburgh. This project received the maximum rating of 10. Project 06, “Recovery Act: Advanced Hydrogen Turbine Development,” conducted by Siemens Energy, received a high rating of 8.

General Project Weaknesses

Several recurring themes arose during this peer review. The panel considered it a weakness that some project teams did not adequately address how the results of their predictive or experimental work will translate to industrial applications of hydrogen turbine technologies. For example, certain modeling simulation efforts were not properly validated with the results of experimental work to demonstrate that the results will meet DOE’s program goals. In other cases, teams did not fully consider how the scale-up of test technologies would impact their assumptions of realistic industrial field conditions.

Another theme identified by the panel was the mismatch of reported progress with the overall timeline of the project. The panel indicated that some project milestones do not have quantifiable targets that enable progress to be tracked against overall project goals. Additionally, panel members expressed concern that some project teams have multiple major tasks and milestones clustered near the end of the project, which presents a risk that the teams will not meet their target goals.

General Project Observations and Recommendations

While the majority of the recommendations provided by the panel were technical in nature and specific to a particular project’s technology or approach, several overarching themes did emerge. To ensure that the project technologies meet the stated program goals and are on a viable path to commercialization, the panel suggested that project teams continue to leverage the work and expertise of other project teams within the program to ensure that all teams are using the best available data and resources. The panel also recommended that the project teams produce detailed plans of future work including quantifiable milestones to ensure that they meet their stated goals within the remaining budget and timeline. These recommendations would place the project teams and the Hydrogen Turbines Program as a whole in a better position to develop technologies that are suitable for real-world hydrogen-fueled combined cycle power systems.

PROJECT SYNOPSES

For more information on the Hydrogen Turbines Program and project portfolio please visit the NETL website: http://www.netl.doe.gov/research/coal/energy-systems/turbines/.

01: OPPB/PD-1
ASSESSMENT OF SUPERCRITICAL CO_2 CYCLES

Kristin Gerdes, National Energy Technology Laboratory
Charles White, Noblis, Inc.

2012 Technology Readiness Level: N/A
DOE Funding: $330,000
Cost Share: $0
Duration: 8/8/2012 – 11/14/2014

Project Evaluation Score
N/A

The overall project objective is to evaluate the potential of fossil fuel-based supercritical carbon dioxide (sCO_2) power cycles to provide significant efficiency improvement and cost of electricity reductions relative to state-of-the-art and other advanced power cycle technologies. The project is also working to identify key system-level features and/or parameters for sCO_2 power cycle success (e.g., temperature, configuration).

02: FE0011822
EFFECTS OF EXHAUST GAS RECIRCULATION (EGR) ON TURBULENT COMBUSTION AND EMISSIONS IN ADVANCED GAS TURBINE COMBUSTORS WITH HIGH-HYDROGEN-CONTENT (HHC) FUELS

Robert Lucht, Purdue University

2012 Technology Readiness Level: N/A
DOE Funding: $500,000
Cost Share: $150,355
Duration: 10/01/13 – 09/30/16

Project Evaluation Score
2

The primary goal of this project is to develop experimental methods, kinetic models, and numerical tools to quantify and predict the impact of exhaust gas recirculation (EGR) on nitrogen oxides and carbon monoxide emissions, combustion kinetics, radiation heat transfer, turbulent combustion, and combustion instabilities for high-hydrogen-content fuels by using laminar and turbulent flow reactors and gas turbine combustors operating at high temperatures and pressures. The project will provide detailed data for improving chemical kinetic models of EGR effects, supply insights into the effects of EGR on flame speeds and turbulent flame structure, and assess the impact of EGR on emissions in a high-pressure combustion test rig.

03: FE0011875
THERMALLY EFFECTIVE AND EFFICIENT COOLING TECHNOLOGIES FOR ADVANCED GAS TURBINES

Forrest Ames, University of North Dakota

2012 Technology Readiness Level: N/A
DOE Funding: $499,996
Cost Share: $124,998
Duration: 10/01/13 – 09/30/16

Project Evaluation Score
5

The primary goal of the project is to research and develop three cooling methods for improved turbine airfoil cooling performance: 1) incremental impingement for the leading edge; 2) counter cooling for the pressure and suction surfaces; and 3) sequential impingement for the pressure and suction surfaces of the vane. These methods are designed to improve the internal thermal effectiveness of the cooling air used before discharging the spent air onto the surface to form an optimal film cooling layer to thermally protect (i.e., reduce the heat load of) the surface.

04: FWP-2012.03.02 TASKS 2, 3, AND 4
TURBINE THERMAL MANAGEMENT: NEAR SURFACE EMBEDDED MICRO-CHANNEL (NSEMC) COOLING

Mary Anne Alvin, National Energy Technology Laboratory
Iver Anderson, Ames Laboratory
Minking Chyu, University of Pittsburgh

2012 Technology Readiness Level: 3
DOE Funding: $3,240,000
Cost Share: $0
Duration: 10/01/11 – 9/30/14

Project Evaluation Score
10

The overall project goal is to develop basic and applied technology in the areas of heat transfer, materials development, and secondary flow control. Specifically, the project aims to develop novel, manufacturable, internal airfoil cooling technology concepts that achieve a cooling enhancement factor of approximately five over that of smooth, airfoil cooling channel passages; develop advanced, manufacturable airfoil film cooling concepts that achieve a 50 percent reduction in required cooling flow; design, construct, and operate a world-class test facility for testing advanced sealing improvement strategies for the turbine rotating blade platform to ultimately reduce fuel burn; and develop advanced material system architectures that permit operation of turbine airfoils at temperatures at least 50°C–100°C higher than current state-of-the-art components.

05: FWP-FEAA112
MATERIALS ISSUES IN SUPERCRITICAL CARBON DIOXIDE
Bruce A. Pint, Oak Ridge National Laboratory

2012 Technology Readiness Level: N/A
DOE Funding: $450,000
Cost Share: $0
Duration: 10/01/12–09/30/14

Project Evaluation Score
5

The proposed work is focused on establishing a broad understanding of the materials issues associated with scaling up supercritical carbon dioxide (sCO_2) systems to higher temperatures in order to increase the efficiency of commercial power production. The effort is intended to increase understanding of the applicable corrosion mechanisms in sCO_2 as a function of temperature and establish temperature limits for various classes of materials (e.g., ferritic and austenitic steels, nickel-based alloys, and alumina-forming alloys) to enable materials selection and design of sCO_2 systems.

06: FC26-05NT42644
RECOVERY ACT: ADVANCED HYDROGEN TURBINE DEVELOPMENT
John Marra, Siemens Energy, Inc.

2012 Technology Readiness Level: 4–5
DOE Funding: $49,791,168
Cost Share: $20,761,010
Duration: 10/01/05 – 06/30/15

Project Evaluation Score
8

The overall project goal is to identify a set of gas turbine technology advancements that will improve the efficiency, emissions, and cost performance of gas turbines for industrial applications with carbon capture and storage. This extension will accelerate the key technologies needed to significantly improve the efficiency of gas turbines in industrial applications, apply these technologies to the advanced hydrogen turbine, and adapt to existing turbine frames as applicable.

Specifically, the project will evaluate, downselect, and validate advanced technologies and concepts including a fuel-flexible, ultra-low nitrogen oxide, long-life combustion system operating at the increased firing temperatures needed to achieve high efficiency; higher temperature materials system capabilities that allow operation in challenging environments; advanced manufacturing processes and techniques that can produce novel turbine cooling schemes; and sensor designs for engine validation or use in online control.

APPENDIX A: ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Definition
ARRA	American Recovery and Reinvestment Act
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
DOE	U.S. Department of Energy
EGR	exhaust gas recirculation
FY	fiscal year
GE	General Electric
GTC	Gasification Technologies Council
HHC	high hydrogen content
IGCC	integrated gasification combined cycle
IPO	Independent Professional Organization
LTI	Leonardo Technologies, Inc.
MIT	Massachusetts Institute of Technology
MW	megawatt
NETL	National Energy Technology Laboratory
NOx	nitrogen oxide
NPS	Naval Postgraduate School
NSEMC	near surface embedded micro-channel
O_2	oxygen
OPPB	Office of Program Performance & Benefits
ORD	Office of Research & Development
PI	principal investigator
ppm	parts per million
R&D	research and development
RD&D	research, development, and demonstration
RUA	Regional University Alliance
SBIR	Small Business Innovation Research
scfm	standard cubic feet per minute
SCIES	South Carolina Institute for Energy Studies
sCO_2	supercritical carbon dioxide
TRL	technology readiness level
UTSR	University Turbine System Research

APPENDIX B: PEER REVIEW EVALUATION CRITERIA FORM

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

FY13 HYDROGEN TURBINES PEER REVIEW

APRIL 14–15, 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.

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." 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 Hydrogen Turbines Peer Review

April 14 – 15, 2014

Sheraton Station Square
Pittsburgh, PA

Monday, April 14, 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 – Klaus Brun, Southwest Research Institute (SwRI) - 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 - Hydrogen Turbines Technology Manager – Richard Dennis, NETL
9:15 – 9:30 a.m.	**BREAK**
9:30 – 10:15 a.m.	**Office of Program Performance & Benefits (OPPB) Support to the Hydrogen Turbines Program – Overview** *Kristin Gerdes,* **National Energy Technology Laboratory** *Charles White,* **Noblis, Inc.**
10:15 – 10:35 a.m.	Q&A/Discussion
10:35 – 11:20 a.m.	**01 – Project # OPPB/PD-1** – Assessment of Supercritical CO_2 Cycles *Kristin Gerdes,* **National Energy Technology Laboratory** *Charles White,* **Noblis, Inc.**
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 # FE0011822** – Effects of Exhaust Gas Recirculation (EGR) on Turbulent Combustion and Emissions in Advanced Gas Turbine Combustors with High-Hydrogen-Content (HHC) Fuels *Robert Lucht,* **Purdue University**
1:15 – 1:45 p.m.	Q&A
1:45 – 3:00 p.m.	Discussion
3:00 – 3:15 p.m.	**BREAK**

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3:15 – 3:45 p.m.	**03 – Project # FE0011875** – Thermally Effective and Efficient Cooling Technologies for Advanced Gas Turbines *Forrest Ames,* **University of North Dakota**
3:45 – 4:15 p.m.	Q&A
4:15 – 5:30 p.m.	Discussion

Tuesday, April 15, 2014 – Waterfront Room

7:00 – 8:00 a.m.	**Registration – Admiral Foyer**
8:00 – 8:30 a.m.	**04 – Project # FWP-2012.03.02 Tasks 2, 3 and 4** – Turbine Thermal Management: Near Surface Embedded Micro-channel (NSEMC) Cooling *Mary Anne Alvin,* **National Energy Technology Laboratory** *Iver Anderson,* **Ames Laboratory** *Minking Chyu,* **University of Pittsburgh**
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 # FWP-FEAA112** – Materials Issues in Supercritical Carbon Dioxide *Bruce A. Pint,* **Oak Ridge National Laboratory**
11:00 – 11:30 a.m.	Q&A
11:30 – 12:45 p.m.	Discussion
12:45 – 1:45 p.m.	**Lunch (on your own)**
1:45 – 2:30 p.m.	**06 – Project # FC26-05NT42644** – Recovery Act: Advanced Hydrogen Turbine Development *John Marra,* **Siemens Energy, Inc.**
2:30 – 3:15 p.m.	Q&A
3:15 – 4:30 p.m.	Discussion
4:30 – 4:45 p.m.	**BREAK**
4:45 – 6:15 p.m.	**Wrap-up Session**

APPENDIX E: PEER REVIEW PANEL MEMBERS

Klaus Brun, Ph.D. – Panel Chair

Dr. Brun is the Program Director of the Machinery Program at Southwest Research Institute. His experience includes positions in engineering, project management, and management at Solar Turbines, General Electric, and Alstom. He holds six patents, authored over 150 papers, and co-authored two textbooks on gas turbines and compressors. Dr. Brun won an R&D 100 award in 2007 for his Semi-Active Valve invention and ASME Oil and Gas Committee Best Paper awards in 1998, 2000, 2005, 2009, 2010, and 2012. He was chosen to the "40 under 40" by the San Antonio Business Journal. He is the past chair of the American Society of Mechanical Engineers (ASME)-International Gas Turbine Institute (IGTI) Board of Directors and the past Chairman of the ASME Oil and Gas Applications Committee. He is also a member of the American Petroleum Institute 616 and 690 Task Forces, the Middle East Turbomachinery Symposium, the Fan Conference Advisory Committee, and the Supercritical CO_2 Conference Advisory Committee. Dr. Brun is the Executive Correspondent and columnist of *Turbomachinery International Magazine* and an Associate Editor of the ASME *Journal of Gas Turbines and Power*.

Dr. Brun's research interests are in the areas of turbomachinery aero-thermal fluid dynamics, process system analysis, energy management, advanced thermodynamic cycles, instrumentation and measurement, and combustion technology. He is widely experienced in performance prediction; off-design function; degradation; uncertainty diagnostics; and root cause failure analysis of gas turbines, combined cycle plants, integrated gasification combined cycle plants, centrifugal compressors, steam turbines, and pumps.

Dr. Brun received a B.S. in aerospace engineering from the University of Florida and an M.S. and Ph.D. in mechanical and aerospace engineering from the University of Virginia.

James Heidmann, Ph.D.

Dr. Heidmann has worked at NASA Glenn Research Center from 1988 to present as an aerospace engineer, publishing over 20 research papers and journal articles in the area of turbomachinery aerodynamics and heat transfer. He was elected a fellow of the American Society of Mechanical Engineers (ASME) in 2007. Since 2012, Dr. Heidmann has served as manager of NASA's Aeronautical Sciences Project. Prior to this, Dr. Heidmann served as Chief of the Turbomachinery and Heat Transfer Branch at NASA Glenn.

Dr. Heidmann received his B.S. in mechanical engineering from the University of Toledo, his M.S. in mechanical engineering from Purdue University, and his Ph.D. in mechanical and aerospace engineering from Case Western Reserve University.

Knox Millsaps, Jr., Ph.D.

Knox T. Millsaps has been the chair of the Department of Mechanical and Aerospace Engineering at the Naval Postgraduate School (NPS) in Monterey, California since 2008, and has been the director of the NPS Marine Propulsion Laboratory, where he conducts research in the area of power and propulsion, since 1996. Other positions he has held at NPS include associate chairman of the Department of Mechanical and Astronautical Engineering from 2002 to 2007, associate provost of academic affairs from 2005 to 2006, and associate provost of institutional development from 2006 to 2007.

Dr. Millsaps' teaching interests span power and propulsion, fluid mechanics, thermodynamics, energy conversion, and heat transfer. His research interests include turbomachinery, power and propulsion, rotordynamics, fluid structure interactions, condition-based maintenance of rotating and reciprocating machinery, advanced energy systems, and alternate and synthetic fuels.

Prior to his work at NPS, Dr. Millsaps worked for Pratt & Whitney (both Florida and Connecticut) in the 1980s, working on unsteady, three-dimensional flow. Knox served two years as congressional staff in the Office of Representative John M. Spratt (Chairman, House Budget Committee and Senior Member, House Armed Services Committee). From 2000 to 2001, Dr. Millsaps was a Brookings Legislative Fellow in the office of Representative John M. Spratt, Jr., working on procurement and research and development issues, missile defense, DOE weapons laboratories (National Nuclear Security Administration and stockpile stewardship), strategic forces, space assets, electronic warfare, and procurement reform.

Dr. Millsaps is past chair of the board of directors of the ASME International Gas Turbine Institute, editor-in-chief of *Global Gas Turbine News*, a member of ASME and the American Institute of Aeronautics and Astronautics, and associate editor of the ASME *Journal of Gas Turbines and Power*. Additionally, he has served as a member of the ASME Board on Government Affairs and the ASME Energy Committee. In 2005, Dr. Millsaps received an award for Best Paper from the International Gas Turbine Institute, Marine Committee.

Dr. Millsaps received a B.S. in engineering science and physics from the University of Florida in 1983, M.S. in aero/astro from the Massachusetts Institute of Technology (MIT) in 1986, and a Ph.D. in aero/astro and finance from MIT (Sloan and Harvard Business School) in 1991.

Douglas M. Todd

Douglas Todd is the owner and president of Process Power Plants LLC, a consulting company dedicated to integrating gas turbine combined cycles with gasification systems (IGCC) to provide clean, economical electric power and other useful products from low-cost fuels. Mr. Todd's industry experience includes 35 years with General Electric (GE) in engineering, marketing, and product management positions, culminating with business management responsibility for GE's Process Power Plants Organization. Mr. Todd developed and introduced combined cycle and IGCC power plant technology on a worldwide basis.

Recent gas turbine technology development combined with technology partnerships have led to 20 successful IGCC projects, including co-production plants that account for 14 of these projects. Mr. Todd has led the IGCC power block technology into a variety of process power plant applications for co-production of power and hydrogen, clean fuels, gas-to-liquids, and carbon dioxide reduction technologies. By applying integration techniques and unique modifications in the power block, various process technologies can be enhanced, improving economics and extending commercial applications for these processes.

Mr. Todd is a member of the American Institute of Chemical Engineers, the Gasification Technologies Council (GTC), and Energy Frontiers International. He received the first European Institution for Chemical Engineers Medal for Excellence in Gasification in 2002 and the GTC Lifetime Achievement Award in 2003. Mr. Todd has published numerous technical papers for various entities including ASME and the Electric Power Research Institute. Mr. Todd received a

B.S. degree in chemical engineering from Worcester Polytechnic Institute.

Richard Wenglarz, Ph.D.

Richard Wenglarz is a consultant for advanced energy systems, particularly related to gas turbines. His energy system experience includes about 23 years at major energy companies and, most recently, 10 years at the South Carolina Institute for Energy Studies (SCIES) at Clemson University.

At SCIES, Dr. Wenglarz was Manager of Research for the University Turbine Systems Research program organized as a consortium of government, industry, and about 110 member universities. Working with an industrial review board of up to 17 member companies (e.g., General Electric, ExxonMobil, British Petroleum, Siemens, etc.), he was responsible for defining request-for-proposal research objectives, evaluating and selecting university proposals to accomplish the objectives, and overseeing the university research projects awarded throughout the nation. He also oversaw workshops to disseminate the results of the university research to Government, industry, and academia.

Prior to SCIES, Dr. Wenglarz held research and project management positions over about 23 years related to advanced turbine systems at Rolls Royce/Allison Gas Turbine Company and Westinghouse Research and Development Center. He managed a program that successfully demonstrated an Allison 501 gas turbine with first-stage ceramic vanes at an Exxon natural gas processing plant. He also conducted numerous plant economic analyses for the DOE/Allison Advanced Turbine System and the DOE/Allison Direct Coal Fired Turbine System Program. In addition, Dr. Wenglarz was responsible for developing and evaluating turbine flow path protection approaches from deposition, erosion, and corrosion for the Allison Direct Coal Fired Turbine Program and at Westinghouse. He also managed the Allison internal research and development program for coal fuels and the DOE/Allison Component Screening Program, both directed to developing a technology base for direct coal fueled turbines.

Dr. Wenglarz has authored over 80 publications and has delivered invited presentations at the Von Karman Institute for Fluid Dynamics (Belgium), Yale University, UK Central Electricity Research Laboratories, Cambridge University, the Kentucky Energy Cabinet Laboratories, 8th Liege Conference on Materials for Advanced Power Engineering (Belgium), and the Sultzer Metco Gen 5 Ceramics Consortium. He also developed and presented a course segment on turbine corrosion and deposition at the DOE-sponsored short course “Impact of Synfuels and Hydrogen Fuels Relevant to Gas Turbine Development.”

Dr. Wenglarz received B.S. and M.S. degrees from the University of Illinois and a Ph.D. from Stanford University, all in engineering mechanics.