

OVERVIEW REPORT

DOE/NETL Clean Coal Research Program
Advanced Combustion Systems
FY2014 Peer Review Meeting

Pittsburgh, Pennsylvania
May 19-20, 2014



OVERVIEW REPORT
CLEAN COAL RESEARCH PROGRAM
ADVANCED COMBUSTION SYSTEMS PROGRAM
FY2014 PEER REVIEW MEETING

Pittsburgh, Pennsylvania
May 19–20, 2014

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TABLE OF CONTENTS

Introduction and Background	1
Overview of the Peer Review Process	5
Summary of Key Findings	7
Project Synopses	9
01: NT-43088	9
Recovery Act: Oxy-combustion Oxygen Transport Membrane Development	9
02: FE0009448.....	9
Oxy-Fired Pressurized Fluidized Bed Combustor Development and Scale-up for New and Retrofit Coal-Fired Power Plants.....	9
03: FE0009702.....	10
Staged, High-Pressure Oxy-Combustion Technology: Development and Scale-up.	10
04: FE0009484.....	10
Alstom’s Chemical Looping Combustion Technology with CO2 Capture for New and Retrofit Coal-Fired Power	10
05: FWP-FY11.60.CCSSI (ICMI)	11
Industrial Carbon Management Initiative – Chemical Looping Combustion (ICMI- CLC)	11
06: FE0009761	11
Commercialization of an Atmospheric Iron-Based Coal Direct Chemical Looping (CDCL) Process for Power Production.....	11
Appendix A: Acronyms and Abbreviations.....	12
Appendix B: Peer Review Evaluation Criteria Form	13
Appendix C: Technology Readiness Level Descriptions.....	16
Appendix D: Meeting Agenda.....	17
Appendix E: Peer Review Panel Members.....	20

INTRODUCTION AND BACKGROUND

Advanced Combustion Systems Program Mission and Goals

NETL's Advanced Combustion Systems research and development (R&D) effort is conducted under the Clean Coal Research Program's (CCRP's) Carbon Capture and Storage (CCS) and Power Systems program area. The CCS and Power Systems program conducts and supports long-term, high-risk R&D to significantly reduce fossil fuel power plant emissions (including carbon dioxide [CO₂]) and substantially improve efficiency, leading to viable, near-zero emissions fossil fuel energy systems. The success of NETL research and related program activities will enable CCS technologies to overcome economic, social, and technical challenges, including cost-effective CO₂ capture, compression, transport, and storage through successful CCS integration with power-generation systems.

Advanced combustion power generation from fossil fuels involves combustion in a high-oxygen (O₂) concentration environment rather than in air. This type of system eliminates introduction of most, if not all, of the nitrogen (N₂) found in air into the combustion process, generating flue gas composed of CO₂, water, trace contaminants from the fuel, and other gas constituents that infiltrated the combustion system. The high concentration of CO₂ (≈60 percent) and absence of nitrogen in the flue gas simplify separation of CO₂ from the flue gas for storage or beneficial use. Thus, oxygen-fired combustion is an alternative approach to post-combustion capture for CCS for coal-fired systems. However, the appeal of oxygen-fired combustion is tempered by a number of challenges, namely capital cost, energy consumption, operational challenges associated with supplying O₂ to the combustion system, air infiltration into the combustion system that dilutes the flue gas with N₂, and excess O₂ contained in the concentrated CO₂ stream. These factors mean oxygen-fired combustion systems are not cost-effective at their current level of development. Advanced combustion system performance can be improved either by lowering the cost of oxygen supplied to the system or by increasing the overall system efficiency. The Advanced Combustion Systems Program targets both of these possible improvements through sponsored cost-shared research into two key technologies: 1) oxy-combustion and 2) chemical looping combustion (CLC).

Oxy-combustion power production with carbon capture involves three major components: oxygen production (air separation unit), the oxy-combustion boiler (fuel conversion [combustion] and steam generation unit), and CO₂ purification and compression. Based on different embodiments of these components, oxy-combustion can have several process configurations. These different configurations will have different energetic and economic performance. Today's oxy-combustion system configuration would use a cryogenic process for O₂ separation; atmospheric-pressure combustion for fuel conversion in a conventional supercritical pulverized-coal boiler; substantial flue gas recycle; conventional pollution control technologies for sulfur oxides, nitrogen oxides, mercury, and particulates; and mechanical compression for CO₂ pressurization. However, costs associated with available oxy-combustion technologies are too high. The Advanced Combustion Systems Program is developing advanced technologies to reduce the costs and energy requirements associated with current systems. R&D efforts are focused on development of both atmospheric and pressurized oxy-combustion power generation systems, as well as a membrane-based oxygen separation technology.

In CLC systems, oxygen is introduced to the system via oxidation-reduction cycling of an oxygen carrier—a solid, metal-based compound. It may be in the form of one or more metal oxides (e.g., oxides of copper, nickel, or iron), an oxygen-containing metal compound (e.g., calcium sulfate), or a metal oxide supported on a high-surface-area substrate (e.g., alumina or silica) that does not take part in the reactions. For a typical CLC concept, the process is split

into separate oxidation and reduction reactions that take place in different reactors. In the reducer, which operates at elevated temperature, the metal-based oxygen carrier is reduced and thus provides the oxygen required for fuel combustion. The overall operation of the fuel reactor can be exothermic or endothermic, depending on the fuel, the oxygen carrier, and the reactions taking place within. The combustion product from the fuel reactor is a highly concentrated CO₂ and water stream that can be purified, compressed, and sent to storage or for beneficial use. The reduced metal carrier is then sent to the air reactor (oxidizer), which also operates at elevated temperatures, where it is regenerated to its oxidized state. The air reactor also produces hot, oxygen-depleted flue gas, which is vented. Heat from the process is typically extracted from the hot solids exiting the oxidizer as well as the hot gas streams exiting the oxidizer and reducer; it is used to create steam that drives a turbine to generate power. Current CLC R&D efforts are focused on development and refinement of oxygen carriers with sufficient oxygen capacity that can withstand the harsh conditions associated with CLC operation, development of effective and sustainable solids circulation and separation techniques, reactor design to support fuel and oxygen carrier choices, effective heat recovery and integration, and overall system design and optimization.

The goals of the Advanced Combustion Systems Program support the energy goals established by the CCRP. To drive down the costs of implementing CCS, the CCRP is pursuing research, development, and demonstration of new technologies to decrease the cost of electricity and capture costs and to increase base power plant efficiency, thereby reducing the amount of CO₂ that has to be captured and stored per unit of electricity generated. The CCRP is developing a portfolio of technology options to enable the United States to continue to benefit from using our secure and affordable coal resources. The challenge is to help position the economy to remain competitive, while reducing carbon emissions.

The Advanced Combustion Systems Program has set the following long-term performance goals for CCRP technologies:

- Demonstration-ready in the 2030–2035 timeframe
- Capture >90% of the CO₂ at less than \$40/tonne of CO₂ captured

The R&D to achieve the above goals is under way, and the pace of activities is increasing. The path ahead with respect to advancing CCS technologies, particularly at scale, is very challenging given today's economic risk-averse climate and because no regulatory framework is envisioned in the near term for supporting carbon management.

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 Advanced Combustion Systems 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 May 19–20, to conduct a two-day peer review of selected Advanced Combustion Systems Program research projects supported by NETL.

Overview of Office of Fossil Energy Advanced Combustion Systems Program Research Funding

The total funding of the six projects reviewed, over the duration of the projects, is \$118,501,162. The funding and duration of the six projects that were the subject of this Peer Review are provided in Table 1 below.

TABLE 1. ADVANCED COMBUSTION SYSTEMS PROGRAM PROJECTS REVIEWED

Reference Number	Project No.	Title	Lead Organization	Principal Investigator	Total Funding		Project Duration	
					DOE	Cost Share	From	To
1	NT43088	Recovery Act: Oxy-combustion Oxygen Transport Membrane Development	Praxair, Inc.	Sean Kelly	\$41,188,249	\$23,939,957	04/01/2007	09/30/2015
2	FE0009448	Oxy-Fired Pressurized Fluidized Bed Combustor Development and Scale-up for New and Retrofit Coal-fired Power Plants	Aerojet Rocketdyne	Mark Fitzsimmons	\$12,962,363	\$7,806,226	10/01/2012	09/30/2016
3	FE0009702	Staged, High-Pressure Oxy-Combustion Technology: Development and Scale-up	Washington University in St. Louis	Richard Axelbaum	\$4,277,184	\$1,156,617	10/01/2012	09/30/2016
4	FE0009484	Alstom's Chemical Looping Combustion Technology with CO ₂ Capture for New and Retrofit Coal-Fired Power	Alstom Power, Inc.	Herbert E. Andrus, Jr.	\$8,891,848	\$2,222,962	10/01/2012	09/30/2016
5	FWP-FY11.60.CC SSI (ICMI)	Industrial Carbon Management Initiative - Chemical Looping Combustion (ICMI-CLC)	National Energy Technology Laboratory - Office of Research and Development	Steve Carpenter	\$12,000,000	\$0	11/15/2010	11/14/2014
6	FE0009761	Commercialization of an Atmospheric Iron-Based Coal Direct Chemical Looping (CDCL) Process for Power Production: Phase I	Babcock & Wilcox Power Generation Group, Inc.	Luis Velazquez-Vargas	\$3,244,605	\$811,151	10/01/2012	09/30/2015
				TOTALS	\$82,564,249	\$35,936,913	--	--

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

On May 19–20, 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 Advanced Combustion Systems 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 a project fact sheet, 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 Advanced Combustion Systems 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-minute PowerPoint presentation that was followed by a 30- 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 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, 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, 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 Advanced Combustion Systems Program Peer Review.

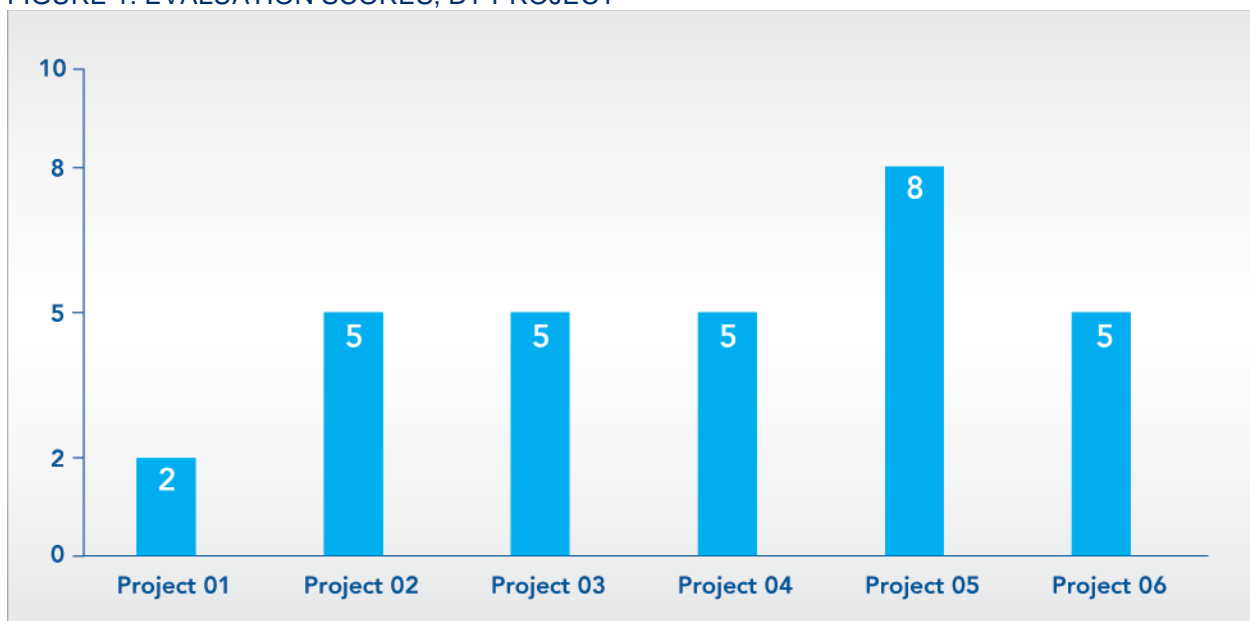
Overview of Project Evaluation Scores

The panel reached consensus on a score for each project:

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

While it is not the intent of this review to directly compare one project with another, a rating of 5 or higher 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 many of the Advanced Combustion Systems Program projects they reviewed. They indicated that the projects represent a diverse set of high-risk, high-reward technologies with ambitious goals and significant potential to advance oxy-combustion and chemical looping combustion (CLC) toward applications in coal-based power generation. Based on the progress made to date by the projects reviewed, the panel was optimistic about the potential for these projects to further progress toward achieving DOE's challenging goals for advancing oxy-combustion technologies that permit low-cost, near-zero emission power generation systems. Panel members noted that the success of projects was largely attributed to the inclusion of highly qualified partners, achieving or showing potential to

demonstrate autothermal operation, and applying strong modeling efforts in combination with experimental work to validate data.

The highest-rated project was project 05, “Industrial Carbon Management Initiative – Chemical Looping Combustion (ICMI-CLC),” conducted by NETL. This project received a rating of 8.

General Project Weaknesses

Five of the six projects received a rating of 5 or higher. Common themes that panel members noted as project weaknesses included not adequately addressing the design requirements and expected conditions for system turndown, neglecting to resolve concerns of system contaminants and their impact on waste disposal, not linking milestones to key technical risks, and not fully capitalizing on the strengths and expertise of all listed project team members and other NETL research teams.

General Project Observations and Recommendations

The panel members offered recommendations that were technical in nature and specific to a particular project’s technology or approach. Since the panel indicated that most of the projects are on track to meet the stated program goals and are on a viable path to commercialization, the panel’s recommendations directly addressed the aforementioned weaknesses and offered suggestions to further improve upon project accomplishments. Panel recommendations included conducting detailed modeling efforts coinciding with experimental tests and redefining project milestones to have a greater focus on cost and performance metrics.

PROJECT SYNOPSES

For more information on the Advanced Combustion Program and project portfolio please visit the NETL website: <http://www.netl.doe.gov/research/coal/energy-systems/advanced-combustion>.

01: NT-43088

RECOVERY ACT: OXY-COMBUSTION OXYGEN TRANSPORT MEMBRANE DEVELOPMENT

Sean Kelly, Praxair, Inc.

2012 Technology Readiness Level: 3

DOE Funding: \$41,188,249

Cost Share: \$23,939,957

Duration: 04/01/2007 – 09/30/2015

Project Evaluation Score

2

Phase III of the project will start with significant efforts related to design of the oxygen transport membrane (OTM) modules and systems. Once first-generation modules are completed, the modules will be integrated in a development-scale reactor and corresponding balance-of-plant designed for a nominal 160,000 standard cubic feet per day (scfd) synthesis gas (syngas) production demonstration. Praxair will partner with a global ceramic manufacturing company and work with the company to define and create subsequent generations of OTM modules. The development-scale test system will be modified as necessary to allow testing of OTM modules as improvements are introduced. There will be additional scope associated with the development-scale syngas system design to convert it to a combustion system capable of transferring heat to a load.

02: FE0009448

OXY-FIRED PRESSURIZED FLUIDIZED BED COMBUSTOR DEVELOPMENT AND SCALE-UP FOR NEW AND RETROFIT COAL-FIRED POWER PLANTS

Mark Fitzsimmons, Aerojet Rocketdyne

William Follett, Aerojet Rocketdyne

2012 Technology Readiness Level: N/A

DOE Funding: \$12,962,363

Cost Share: \$7,806,226

Duration: 10/01/2012 – 09/30/2016

Project Evaluation Score

5

This project will evaluate a novel process for pressurized oxy-combustion in a fluidized bed reactor. Pressurized combustion in oxygen and the recycling of carbon dioxide (CO₂) gas eliminates the presence of nitrogen and other constituents of air, thus minimizing the generation of pollutants and enabling the economic capture of CO₂ gas.

03: FE0009702

STAGED, HIGH-PRESSURE OXY-COMBUSTION TECHNOLOGY:
DEVELOPMENT AND SCALE-UP*Richard Axelbaum, Washington University in St. Louis**Ben Kumfer, Washington University in St. Louis***2012 Technology Readiness Level:** N/A**DOE Funding:** \$4,277,184**Cost Share:** \$1,156,617**Duration:** 10/01/2012 – 09/30/2016

Project Evaluation Score

5

The project will develop and test a staged, pressurized oxy-combustion process and evaluate the economics of the system. The process incorporates a fuel-staged combustion mode for power plants designed for carbon management. The approach permits control of temperature and heat flux associated with oxy-combustion. The potential benefits of the process are higher efficiency and lower capital and operating costs. Reduced gas volumes, oxygen and auxiliary power demands, and increased carbon dioxide purity in the flue gas are additional anticipated benefits.

04: FE0009484

ALSTOM'S CHEMICAL LOOPING COMBUSTION TECHNOLOGY WITH
CO₂ CAPTURE FOR NEW AND RETROFIT COAL-FIRED POWER*Herbert E. Andrus, Jr., Alstom Power, Inc.***2012 Technology Readiness Level:** N/A**DOE Funding:** \$8,891,848**Cost Share:** \$2,222,962**Duration:** 10/01/2012 – 09/30/2016

Project Evaluation Score

5

Alstom Power, through prior DOE funding, has been developing a limestone-based chemical looping combustion technology. The selected project will continue this work by enabling the full analysis of the process through an engineering system and economic study along with the development of a screening tool for process improvements. Additional analyses include an evaluation of pressurizing the limestone chemical looping combustion process.

05: FWP-FY11.60.CCSSI (ICMI)
INDUSTRIAL CARBON MANAGEMENT INITIATIVE – CHEMICAL
LOOPING COMBUSTION (ICMI-CLC)

Doug Straub, National Energy Technology Laboratory

2012 Technology Readiness Level: N/A

DOE Funding: \$12,000,000

Cost Share: \$0

Duration: 11/15/2010 – 11/14/2014

Project Evaluation Score

8

Researchers at NETL are investigating chemical looping combustion (CLC) technology for carbon dioxide (CO₂) control applications. Rather than pursue step-wise scale-up tests for a single chemical looping application, the research will accelerate the technology development of CLC using data from a suite of experiments (and literature) to calibrate numeric models for desired industrial applications. This approach will benefit from emerging capabilities at NETL, including the Simulation-based Engineering User Center (SBEUC), the Carbon Capture and Simulation Initiative (CCSI), as well as experimental expertise in fluid beds, material characterization, and thermal science. The CLC research at NETL is part of a larger Industrial Carbon Management Initiative (ICMI) which is exploring methods for both capture and utilization of CO₂ from industrial sources.

06: FE0009761
COMMERCIALIZATION OF AN ATMOSPHERIC IRON-BASED COAL
DIRECT CHEMICAL LOOPING (CDCL) PROCESS FOR POWER
PRODUCTION

*Luis G. Velazquez-Vargas, Babcock & Wilcox Power Generation
Group, Inc.*

Doug DeVault, Babcock & Wilcox Power Generation Group, Inc.

2012 Technology Readiness Level: N/A

DOE Funding: \$3,244,605

Cost Share: \$811,151

Duration: 10/01/2012 – 09/30/2015

Project Evaluation Score

5

The project goal is to develop a 550 MW commercial-scale economic case study of Babcock & Wilcox and the Ohio State University's coal direct chemical looping (CDCL) process for carbon dioxide capture and separation that can be used for retrofit, repowering, and/or Greenfield installations. Project objectives are to validate the CDCL process application for power generation through engineering system and economic analyses and to develop an experimental, bench-scale system suitable for addressing the identified technology gaps.

APPENDIX A: ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Definition
AIChE	American Institute of Chemical Engineers
ASU	air separation unit
BYU	Brigham Young University
CCC	Copyright Clearance Center
CCRP	Clean Coal Research Program
CCS	carbon capture and storage
CCSI	Carbon Capture and Simulation Initiative
CCUS	carbon capture, utilization, and storage
CDCL	coal direct chemical looping
CLC	chemical looping combustion
CO ₂	carbon dioxide
DOE	U.S. Department of Energy
FY	fiscal year
ICMI	Industrial Carbon Management Initiative
IGCC	integrated gasification combined cycle
IPO	Independent Professional Organization
LTI	Leonardo Technologies, Inc.
MW	megawatt
N ₂	nitrogen
NETL	National Energy Technology Laboratory
O ₂	oxygen
OTM	oxygen transport membrane
PI	principal investigator
R&D	research and development
RD&D	research, development, and demonstration
SBEUC	Simulation-based Engineering User Center
scfd	standard cubic feet per day
scfm	standard cubic feet per minute
syngas	synthesis gas
TRL	Technology Readiness Level

APPENDIX B: PEER REVIEW EVALUATION CRITERIA FORM

**U.S. DEPARTMENT OF ENERGY (DOE)
NATIONAL ENERGY TECHNOLOGY LABORATORY
FY14 ADVANCED COMBUSTION SYSTEMS PEER REVIEW
MAY 19–20, 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	<p>Degree to which the project, if successful, supports the program's near- and/or long-term goals</p> <ul style="list-style-type: none"> • 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	<p>Degree of project plan technical feasibility</p> <ul style="list-style-type: none"> • 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	<p>Degree to which progress has been made towards the stated project performance and cost/economic* objectives</p> <ul style="list-style-type: none"> • Milestones and reports effectively enable progress to be tracked. • Reasonable progress has been made relative to the established project schedule and budget.
4	<p>Degree to which the project plan-to-complete assures success</p> <ul style="list-style-type: none"> • 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	<p>Degree to which there are sufficient resources to successfully complete the project</p> <ul style="list-style-type: none"> • 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	<p>Excellent - Several major strengths; no major weaknesses; few, if any, minor weaknesses. Strengths are apparent and documented.</p>
8	<p>Highly Successful - Some major strengths; few (if any) major weaknesses; few minor weaknesses. Strengths are apparent and documented, and outweigh identified weaknesses.</p>
5	<p>Adequate - Strengths and weaknesses are about equal in significance.</p>
2	<p>Weak - Some major weaknesses; many minor weaknesses; few (if any) major strengths; few minor strengths. Weaknesses are apparent and documented, and outweigh strengths identified.</p>
0	<p>Unacceptable - No major strengths; many major weaknesses. Significant weaknesses/deficiencies exist that are largely insurmountable.</p>

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.

<p>STRENGTHS</p> <p>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.</p>
<p>WEAKNESSES</p> <p>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.</p>
<p>RECOMMENDATIONS</p> <p>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 <i>ranked</i> from most important to least, based on the major/minor strengths/weaknesses.</p>
<p>GENERAL COMMENTS</p>

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 Advanced Combustion Systems Peer Review

May 19 – 20, 2014

Sheraton Station Square
Pittsburgh, PA

Monday, May 19, 2014 – Ellwood I & II

- 7:30 – 8:30 a.m. **Registration – 2nd Floor Foyer**
- 8:30 – 9:00 a.m. **Peer Review Panel Kick-Off Meeting**
Open to National Energy Technology Laboratory (NETL) and
ASM International staff only
- Review of ASM International Process – Stanley C. Theobald, ASM International
 - Role of ASM International Panel Chair – Ravi Prasad, Helios-NRG, LLC
 - Peer Review Process Overview – David Wildman, Leonardo Technologies, Inc. (LTI)
 - Meeting Logistics – David Wildman, LTI
- 9:00 – 9:15 a.m. **Technology Manager and Panel Q&A** Open to NETL and ASM International staff only
- Advanced Combustion Systems Technology Manager – Richard Dennis, NETL
- 9:15 – 9:30 a.m. **BREAK**
- 9:30 – 10:00 a.m. **01 – Project # NT43088** – Recovery Act: Oxy-combustion Oxygen Transport Membrane
Development
Sean Kelly, Praxair, Inc.
- 10:00 – 10:45 a.m. Q&A
- 10:45 – 12:00 p.m. Discussion
- 12:00 – 1:00 p.m. **Lunch (on your own)**
- 1:00 – 1:30 p.m. **02 – Project # FE0009448** – Oxy-Fired Pressurized Fluidized Bed Combustor Development
and Scale-up for New and Retrofit Coal-Fired Power Plants
Mark Fitzsimmons and William Follett, Aerojet Rocketdyne
- 1:30 – 2:15 p.m. Q&A
- 2:15 – 3:30 p.m. Discussion
- 3:30 – 3:45 p.m. **BREAK**
- 3:45 – 4:15 p.m. **03 – Project # FE0009702** – Staged, High-Pressure Oxy-Combustion Technology:
Development and Scale-up
Richard Axelbaum and Ben Kumfer, Washington University in St. Louis
- 4:15 – 4:45 p.m. Q&A
- 4:45 – 6:00 p.m. Discussion

Tuesday, May 20, 2014 – Ellwood I & II

7:00 – 8:00 a.m.	Registration – 2nd Floor Foyer
8:00 – 8:30 a.m.	04 – Project # FE0009484 – Alstom's Chemical Looping Combustion Technology with CO ₂ Capture for New and Retrofit Coal-Fired Power <i>Herbert E. Andrus, Jr., Alstom Power, Inc.</i>
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 # FWP-FY11.60.CCSSI (ICMI) – Industrial Carbon Management Initiative - Chemical Looping Combustion (ICMI-CLC) <i>Doug Straub, National Energy Technology Laboratory</i>
11:15 – 11:45 a.m.	Q&A
11:45 – 1:00 p.m.	Discussion
1:00 – 2:00 p.m.	Lunch (on your own)
2:00 – 2:30 p.m.	06 – Project # FE0009761 – Commercialization of an Atmospheric Iron-Based Coal Direct Chemical Looping (CDCL) Process for Power Production <i>Luis G. Velazquez-Vargas and Doug DeVault, Babcock & Wilcox Power Generation Group, Inc.</i>
2:30 – 3:00 p.m.	Q&A
3:00 – 4:15 p.m.	Discussion
4:15 – 4:30 p.m.	BREAK
4:30 – 5:30 p.m.	Wrap-up Session

APPENDIX E: PEER REVIEW PANEL MEMBERS

Ravi Prasad, Ph.D. – Panel Chair

Helios-NRG, LLC—President

- Principal investigator (PI) of DOE Small Business Technology Transfer Phase 2 project developing step-change technology to recover helium from low-purity sources using a new separation technology in a hybrid process
- PI of new algae technology for carbon dioxide (CO₂) mitigation, bio-fuel production, and water remediation applications
- Consulted with DOE in application reviews for “CCS from Industrial Sources and Innovative Concepts for Beneficial CO₂ Use,” “Clean Coal Power Initiative—Round 3,” and “Large-Scale Industrial CCS Projects”
- Panelist in 10 NETL peer reviews and Chair of four peer reviews
- Consultant to Praxair on sustainability initiative
- Provided consultation services to industrial clients in clean energy, natural gas processing, CO₂, helium recovery, membrane technology, cryogenic, and other gas separation processes

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

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

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

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

Larry L. Baxter, Ph.D.

Dr. Larry Baxter is a Professor of Chemical Engineering at Brigham Young University (BYU). Dr. Baxter holds B.S. and Ph.D. degrees in chemical engineering and his research focus is sustainable energy systems. Prior to joining the faculty at BYU, Dr. Baxter worked for 14 years at Sandia National Laboratories' Combustion Research Facility. He has written five chapters for books, edited four books, and authored over 70 archival journal publications.

Dr. Baxter's current research involves experimental and theoretical sustainable energy research, including carbon capture and storage, biomass, black liquor, and coal combustion and gasification, diagnostic development, and model development.

Dr. Baxter has an outstanding history of student mentoring. This past year, he directed eight graduate students and mentored 19 undergraduates, published eight papers (all with student coauthors), submitted five patent applications, continued his high level of research funding with \$950K of new funding, and was keynote speaker at the Electric Power Conference. Dr. Baxter regularly collaborates with researchers all over the globe and offers services in a variety of high-profile, professional leadership positions.

Mónica Lupión, Ph.D.

Dr. Mónica Lupión is currently a visiting research scientist at Massachusetts Institute of Technology and an Associate Professor at Universidad de Sevilla. Dr. Lupión was the International Affairs Director at Fundación CIUDEN - Spanish Government from 2008 through 2012. She was also a researcher at the International Energy Agency Greenhouse Gas R&D Programme in 2009, and a process engineer at INERCO, S.A. (Engineering and Engineering Consultancy) from 2002 to 2005.

Dr. Lupión has over 10 years of international experience working on RD&D aspects of energy and climate change, including technical, policy, financial, and management aspects. She has a solid scientific background combined with international relations, project management, and public communication skills.

Dr. Lupión is a member of international organizations related to energy and climate change mitigation, such as the Executive Committee of the International Energy Agency Greenhouse Gas Program, the Technology Task Force and the Communication Group of the European Zero Emissions Platform, Technical Committee EUROGIA+ (cluster of the EUREKA network), Hydrogen and Fuel Cells Platform, and is on the scientific committee of a number of international conferences. Dr. Lupión is the author of more than 40 papers and contributions to international conferences and a researcher/project manager in more than 25 national and international projects.

Dr. Lupión received her B.S. in industrial engineering, and her M.S. and Ph.D. in chemical and environmental engineering from Universidad de Sevilla.

James C. Sorensen

Mr. James Sorensen is a consultant with a primary focus on clean coal and supporting technologies, including integrated gasification combined cycle (IGCC), oxy-fuel combustion, and coal-to-liquids. He is the former chief operating officer and now a senior advisor of GTLpetrol LLC. Prior to founding Sorensenergy, LLC, he worked for Air Products and Chemicals as

director of new markets with responsibility for Syngas Conversion Technology Development and Government Systems; and director of gasification and energy conversion. In the latter position, he had commercial responsibility for numerous studies involving air separation unit (ASU)/gas turbine integration for IGCC. Mr. Sorensen was responsible for the sale of the ASU for the Tampa Electric Polk County IGCC facility, which included the first commercial application of the Air Products cycle for nitrogen integration of the ASU with the gas turbine. He was also involved with gas turbine integration associated with Air Products' ion transport membrane oxygen program. Prior responsibilities included project management of Air Products' baseload liquefied natural gas projects, commercial management of synthetic natural gas production, and general management of the Membrane Systems department.

Mr. Sorensen's technical interests include IGCC, oxy-fuel combustion, gas-to-liquids, and air separation and hydrogen/syngas technology. His programmatic interests include Electric Power Research Institute CoalFleet, Fossil Energy R&D, DOE's Clean Coal Power Initiative, DOE's FutureGen program, and commercial projects. His areas of expertise include project conception and development, consortium development and management, technology and government sales and contracting, (R&D program management), technology consulting and training, commercial contract development, and intellectual property. Mr. Sorensen is the founding chairman of the Gasification Technologies Council, and is vice chairman of both the Council on Alternate Fuels and Energy Futures International. He holds eight U.S. patents, one of which involves ASU/gas turbine integration for IGCC. He is also well published in the area of clean coal.

Mr. Sorensen received his B.S. and M.S. degrees in chemical engineering from California Institute of Technology and Washington State University, respectively, and an MBA from the Harvard Business School.

John C. Tao, Ph.D.

Dr. John Tao has a wealth of experience in gas separations, coal conversion, and combustion technologies through more than 30 years at Air Products and Chemicals. He is currently president of O-Innovation Advisors, a management consulting company that offers partnering, licensing, and government contract services to startups as well as fortune 500 companies worldwide. Prior to starting O-Innovation Advisors, he was vice president of open innovation at Weyerhaeuser, where he managed the corporate intellectual asset management process, technology partnering, and early business development.

At Air Products, Dr. Tao served as corporate director of technology partnerships. He was responsible for worldwide external technology development, intellectual asset management, licensing and technology transfer with outside organizations, and government contracts. He is familiar with oxy-fuel combustion technology and advanced oxygen separation using ion transport membranes. During his career at Air Products, Dr. Tao was involved in engineering management, R&D management, commercial development, venture management, and planning and business development.

Dr. Tao is a Fellow of the American Institute of Chemical Engineers (AIChE). He was a member of the Board of Directors for AIChE, the Industrial Research Institute, the Commercial Development and Marketing Association, and the Council of Chemical Research. He was the chairman of Chemical Industry Environmental Technology Projects, a board member of the Pennsylvania State University Research Foundation, and the chairman of the Management Committee of the Air Products and Imperial College Strategic Alliance, the Air Products Alliance

with Georgia Institute of Technology, and the Air Products/Pennsylvania State University Research Alliance. He served as a member of the Visiting Committee of the Department of Chemical and Petroleum Engineering at the University of Pittsburgh and on the advisory council for the Chemical Engineering Department of the University of Pennsylvania. Dr. Tao has presented and published over 90 papers and holds nine patents.

Dr. Tao received his B.S. and Ph.D. in chemical engineering from Carnegie-Mellon University, and an M.S. in chemical engineering from the University of Delaware.