Final Report
Strategic Center for Coal
Advanced Integrated Gasification Combined Cycle
FY 2010 Peer Review Meeting

MEETING SUMMARY AND RECOMMENDATIONS REPORT

Pittsburgh, Pennsylvania
December 7 – 11, 2009

U.S. DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

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FINAL REPORT
STRATEGIC CENTER FOR COAL
ADVANCED INTEGRATED GASIFICATION COMBINED CYCLE
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DISCLAIMER

The work performed on this task/subtask was completed under Technology & Management Services, Inc. (TMS), Prime Contract DE-AC26-05NT41816 (Subtask 300.01.04) and Leonardo Technologies, Inc. (LTI), Prime Contract DE-FE-0004002 (Subtask 300.01.05) for DOE/NETL.

MEETING SUMMARY AND RECOMMENDATIONS REPORT

EXECUTIVE SUMMARY

The mission of the U.S. Department of Energy's (DOE) Office of Clean Coal (OCC) is to ensure the availability of ultra-clean, near-zero emission, abundant, and low-cost domestic energy from coal in order to fuel economic prosperity, strengthen energy security, and enhance environmental quality. The OCC is organized into nine technology programs. The OCC Advanced Integrated Gasification Combined Cycle (AIGCC) technology program is administered by the DOE Office of Fossil Energy's National Energy Technology Laboratory (NETL). The mission of AIGCC includes the following:

> Lead research and development (R&D) efforts to enhance the performance of gasification systems, thus enabling U.S. industry to improve the competitiveness of gasification-based processes. The gasification program will reduce capital investment, improve the process environmental performance, and increase process reliability and flexibility.
>
> By 2010, develop advanced gasification combined-cycle technologies that can produce electricity from coal at 45-47 percent efficiency based on a higher heating value (HHV) at a capital cost of $1,600 per kilowatt (kW), in constant 2007 dollars.
>
> By 2015, gasification technology will be integrated at pilot-scale with CO_2 separation, capture and sequestration into near-zero atmospheric emissions configurations that can ultimately provide electricity with less than a 10 percent increase in cost of electricity (COE).

In compliance with requirements from the Office of Management and Budget (OMB), 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 FY 2010 Advanced Integrated Gasification Combined Cycle (AIGCC) 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 Technology & Management Services Inc., the American Society of Mechanical Engineers (ASME) convened a panel of seven leading academic and industry experts on December 7–11, 2009 to conduct a five-day Peer Review of selected AIGCC research projects supported by NETL.

Overview of Office of Fossil Energy AIGCC Program Research Funding

The total funding for these 15 projects, over the duration of the projects, is $322,328,009. Of this amount, $186,786,376 (58.0%) is funded by DOE, while the remaining $135,682,633 (42.1%) is funded by project partner cost sharing.

The 15 projects that were the subject of this Peer Review are summarized in Table ES-1 and in Section II of this report.

TABLE ES-1 AIGCC PROJECTS REVIEWED

Reference Number	Project No.	Title	Lead Organization	Principal Investigator	Total Funding[A]		Project Duration[A]	
					DOE	Cost Share	From	To
01	OSAP – GS-10F-0189T / DE-NT0005816	Coal Gasification Technology Pathways: Volume II	Noblis	David Gray	$550,000	$0	05/01/2008	12/15/2009
02	DE-FC26-98FT40343	Development of ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems	Air Products and Chemicals, Inc.	Douglas L. Bennett	$87,011,470	$63,148,392	10/01/1998	09/30/2010
03	DE-FE0000489	High Temperature Syngas Cleanup Technology Scale-Up and Demonstration Project	Research Triangle Institute	Raghubir Gupta	$56,768,241	$56,942,060	07/20/2009	12/31/2014
04	DE-FC26-05NT42459	Integrated Warm Gas Multicontaminant Cleanup Technologies for Coal-Derived Syngas	Research Triangle Institute	Brian Turk	$5,724,245	$1,429,812	06/01/2005	09/30/2011
05	DE-FC26-05NT42458	Development of an Integrated Multicontaminant Removal Process Applied to Warm Syngas Cleanup for Coal-Based Advanced Gasification Systems	Gas Technology Institute (GTI)	Howard Meyer	$1,490,510	$758,122	06/01/2005	05/31/2010
06	DE-FC26-05NT42469	Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants	Eltron Research & Development, Inc.	Douglas S. Jack	$6,332,616	$1,583,164	10/01/2005	09/30/2010
07	DE-FC26-04NT42237	Development of Technologies and Capabilities for Coal Energy Resources	Pratt and Whitney Rocketdyne, Inc. (formerly The Boeing Company)	Alan K. Darby	$15,804,841	$9,507,008	09/30/2004	12/31/2011
08	DE-FC26-06NT42758	Co-Production of Electricity and Hydrogen Using a Novel Iron-Based Catalyst	Research Triangle Institute	Jason P. Trembly	$2,571,888	$643,200	03/30/2006	05/31/2010
09	DE-FC26-99FT40685	Single-Crystal Sapphire Optical Fiber Sensor Instrumentation	Virginia Polytechnic Institute & State University	Anbo Wang	$3,162,623	$831,270	10/01/1999	08/31/2012
10	OSAP – 401.01.13	GHG Reductions in the Power Industry Using Domestic Coal and Biomass	National Energy Technology Laboratory	Michael Matuszewski	$263,044	$0	07/02/2008	08/21/2009
11	ORD-10-220615.1 / ORD-10-220663.9	Fuel Flexible Advanced Energy Systems for the Production of Syngas	National Energy Technology Laboratory	Bryan Morreale	$1,637,000	$0	10/01/2008	09/30/2010
12	ORD-09-220677-T02	Dynamic Simulation and Control of Advanced Power Generation Systems	National Energy Technology Laboratory	Stephen Zitney	$511,480	$0	10/01/2008	09/30/2009
13	DE-FC26-07NT43094	Development of Model Based Controls for GE's Gasifier and Syngas Cooler	General Electric Global Research	Aditya Kumar	$2,413,478	$603,370	07/05/2007	07/05/2010
14	OSAP – 401.01.14	Cost and Performance Baseline for Fossil Energy Plants - Volume 3: Low Rank Coal and Natural Gas to Electricity	National Energy Technology Laboratory	Jeffrey Hoffmann	$1,600,000	$0	11/01/2006	11/06/2009
15	DE-NT04397	Arrowhead Center to Promote Prosperity and Public Welfare in New Mexico	New Mexico State University	James T. Peach	$944,940	$236,235	08/25/2008	09/30/2011
				TOTALS	$186,786,376	$135,682,633		

Note: A: Funding amounts and project durations have been obtained from project summaries submitted by the principal investigator.

NETL ADVANCED INTEGRATED GASIFICATION COMBINED CYCLE PROGRAM OVERVIEW

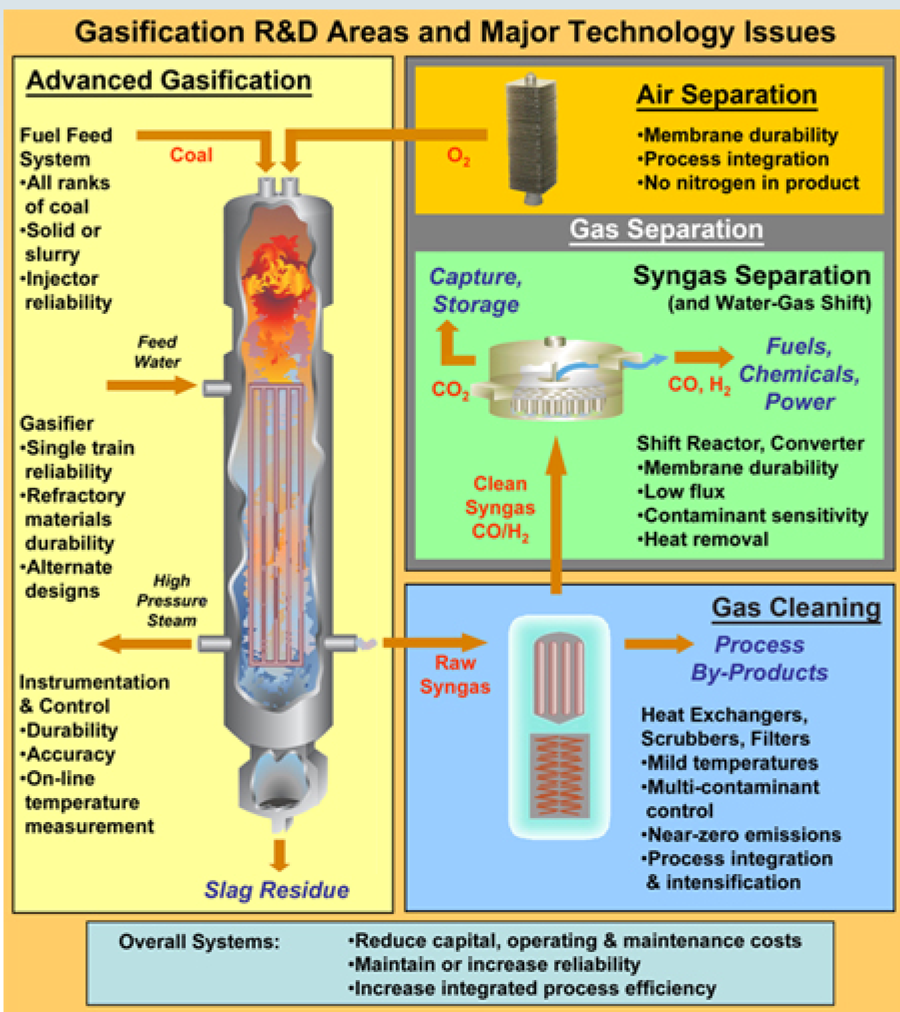
The NETL Advanced Integrated Gasification Combined Cycle Program is part of Fossil Energy's Clean Coal Research Program. The strategic objective of the Clean Coal Research Program is to create public-private partnerships aimed at developing innovative technologies, including technologies that ensure continued electricity production from extensive U.S. fossil fuel resources, particularly coal, and permit compliance with emerging regulations at a reasonable cost.

Mission

The Mission of the NETL Advanced Integrated Gasification Combined Cycle program is to lead R&D efforts to enhance the performance of gasification systems, thus enabling U.S. industry to improve the competitiveness of gasification-based processes. The gasification program will reduce equipment costs; improve the environmental performance of the process; and increase process reliability and flexibility.

Program Areas:

- Advanced Gasification
- Gas Cleaning and Conditioning
- Gas Separation
- Systems Analysis/Product Integration



Overview of the Peer Review Process

NETL requested that ASME assemble an Advanced Integrated Gasification Combined Cycle Peer Review Panel ("Panel") of recognized technical experts to provide recommendations on how to improve the management, performance, and overall results of each individual research project. Each project team prepared a detailed project information form containing an overview of the project's purpose, objectives, and achievements, and a presentation to be given at the Peer Review meeting. The Panel received the project information forms and presentations prior to the Peer Review meeting.

At the meeting, each research team made an uninterrupted 45 to 90 minute PowerPoint presentation that was followed by a 30 to 40 minute question-and-answer (Q&A) session with the Panel. After the principal investigator (PI) and project team left the room, the Panel had a 40 minute discussion about the strengths, weaknesses, recommendations, and action items for each project. All sessions, in order to facilitate a more open and free discourse of project related material with the Panel, were closed, limited to the Panel, ASME, project team members, and DOE/NETL personnel to ensure open discussions between the project team and the Panel.

After the group discussions, each Panel member individually evaluated the 15 projects, providing written comments based on a predetermined set of review criteria. For each of the nine review criteria, the individual reviewer was asked to score the project as one of the following:

Effective (5)

Moderately Effective (4)

Adequate (3)

Ineffective (2)

Results Not Demonstrated (1)

The Panel occasionally had divergent views of a project. In the extreme case, this divergence is reflected in projects receiving both 1 and 5 ratings in a particular criterion. This result should not be taken as an indication that the Panel was indecisive; rather, this reflects the varied backgrounds and differing perspectives of a diverse Panel. Such diversity is a strength allowing the Panel, as a whole, to review a wide range of projects on varied topics with a comparable overall level of expertise.

Figure ES-2 shows the overall average score, over all nine review criteria, for the 15 projects.

FIGURE ES-2 **AVERAGE SCORING, BY PROJECT**

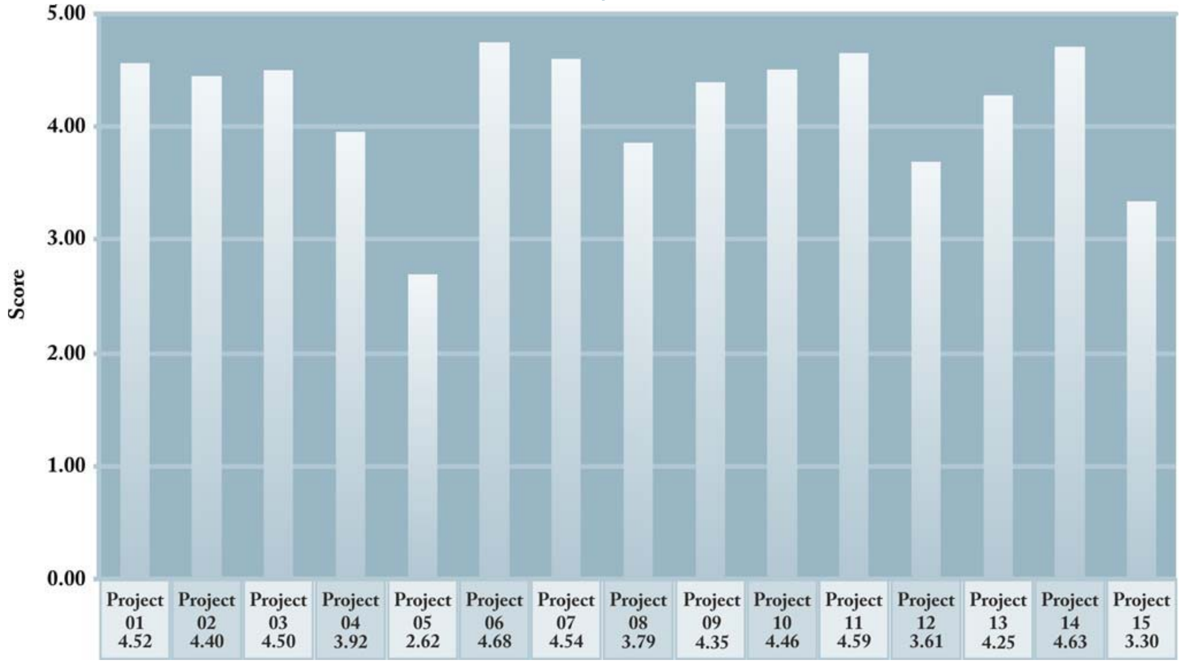


Table ES-3 shows the overall average across all 15 projects reviewed, as well as the highest and lowest averages for an individual project for each of the nine review criterion.

TABLE ES-3 **AVERAGE SCORING, BY REVIEW CRITERION**

Criterion	Project Average	Highest Project Average	Lowest Project Average
1. Scientific and Technical Merit	4.3	5.0	2.7
2. Existence of Clear, Measurable Milestones	4.2	5.0	2.6
3. Utilization of Government Resources	4.3	4.7	2.4
4. Technical Approach	4.2	4.7	2.4
5. Rate of Progress	4.1	5.0	2.6
6. Potential Technology Risks Considered	3.9	4.6	2.4
7. Performance and Economic Factors	4.0	5.0	2.6
8. Anticipated Benefits, if Successful	4.4	5.0	2.9
9. Technology Development Pathways	4.0	4.7	2.7

For more on the overall evaluation process and the nine review criteria, see Section III.

Each project was categorized based on its stage of development, which ranged from fundamental research to proof-of-concept, as described in Table ES-4. This was done to enable the Panel to appropriately score the Performance and Economic Factors and Technology Development Path criteria, providing context for anticipated level of economic and developmental data.

TABLE ES-4 DESCRIPTION OF DEVELOPMENT STAGES

Stage of Research	Description
Fundamental Research	The project explores and defines technical concepts or fundamental scientific knowledge. Projects are laboratory-scale and, traditionally but not exclusively, are the province of academia.
Applied Research	The project presents a laboratory- or bench-scale proof of the feasibility of potential applications of a fundamental scientific discovery.
Prototype Testing	The project develops and tests a prototype technology or process in the laboratory or field, maintaining predictive modeling or simulation of performance and evaluating scalability.
Proof-of-Concept	The project develops and tests a pilot-scale technology or process for field testing and validation at full scale, but is not indicative of a long-term commercial installation.
Major Demonstration Not applicable in this peer review.	The project develops a commercial-scale demonstration of energy and energy-related environmental technologies, generally with the intent of becoming the initial representation of a long-term commercial installation.

A summary of key project findings as they relate to individual projects can be found in Section IV of this report. Process considerations and recommendations for future project reviews are found in Section V.

For More Information

For more information concerning the contents of this report, contact the NETL Peer Review Coordinator, José D. Figueroa, at (412) 386-4966 or Jose.Figueroa@netl.doe.gov.

I. INTRODUCTION

In 2009, the American Society of Mechanical Engineers (ASME) was invited to provide an independent, unbiased, and timely peer review of selected projects within the U.S. Department of Energy (DOE) Office of Fossil Energy Advanced Integrated Gasification Combined Cycle (AIGCC) program (administered by the Office of Fossil Energy's National Energy Technology Laboratory [NETL]). On December 7–11, 2009 ASME convened a panel of seven leading academic and industry experts to conduct a five-day peer review of selected AIGCC research projects supported by NETL. This report contains a summary of the findings from that review.

Compliance with Office of Management and Budget (OMB) Requirements

DOE, the Office of Fossil Energy, and NETL are fully committed to improving the quality and results of their projects. The peer review of selected projects within the AIGCC program was designed to comply with requirements from the Office of Management and Budget.

ASME Center for Research and Technology Development (CRTD)

All requests for peer reviews are organized under ASME's Center for Research and Technology Development (CRTD). CRTD's Director of Research, Dr. Michael Tinkleman, with advice from the chair of the ASME Board on Research and Technology Development, selects an executive committee of senior ASME members that is responsible for reviewing and approving all Panel members and ensuring that there are no conflicts of interest within the Panel or the review process. In consultation with NETL, ASME formulates the review meeting agenda, provides information advising the PIs and their colleagues on how to prepare for the review, facilitates the review session, and prepares a summary of the results. A more extensive discussion of the ASME peer review methodology used for the AIGCC Peer Review Meeting is provided in Appendix A. A copy of the meeting agenda is provided in Appendix B, and profiles of the Panel members are provided in Appendix C.

Overview of the Peer Review Process

ASME was selected as the independent organization to conduct a five-day peer review of 15 AIGCC projects. ASME performed this project review work as a subcontractor to Technology & Management Services, Inc. (TMS), and Leonardo Technologies, Inc., NETL prime contractors. NETL selected the 15 projects, while ASME organized an independent review panel of seven leading academic and industry power plant technology experts. Prior to the meeting, principal investigators (PIs) submitted an 11-page written summary (Project Information Form) of their project's purpose, objectives, and progress. The PI's also submitted their PowerPoint Presentations to the Panel prior to the meeting. This project information, available prior to the meeting, allows the Panel to come to the meeting fully prepared with the necessary project background information.

At the meeting, each research team made a 45 to 90 minute oral presentation, followed by a 30 or 40 minute question-and-answer (Q&A) session with the Panel and a 40 minute Panel discussion of each project. The length of the presentation and Q&A session depended primarily on the perceived time requirement for the PI to go through the presentation material due to a number of factors, such as the project's complexity, duration, and breadth of scope. Based on lessons learned from prior peer reviews and the special circumstances associated with AIGCC program research, ASME decided that both the PI presentations and question-and-answer sessions with the Panel for the AIGCC Peer Review were to be held as closed sessions, limited to the Panel, ASME, project team members, and DOE/NETL personnel. The closed sessions ensured open discussions between the PIs and the Panel. Panel members were also instructed to hold confidential the discussions that took place during the Q&A session.

Each Panel member individually evaluated the project presented and provided written comments based on a predetermined set of review criteria. This publically available document, prepared by ASME, provides a general overview of the AIGCC Peer Review and the projects reviewed therein.

Peer Review Criteria and Peer Review Criteria Forms

ASME developed a set of agreed-upon review criteria to be applied to the projects reviewed at this meeting. ASME provided the Panel and PIs with these review criteria in advance of the Peer Review Meeting, and assessment sheets with the review criteria were pre-loaded (one for each project) onto laptop computers for each Panel member. During the meeting, the Panel members assessed the strengths and weaknesses of each project before providing both recommendations and action items. A more detailed explanation of this process and a sample Peer Review Criteria Form are provided in Appendix D.

The following sections of this report summarize findings from the AIGCC Program Peer Review Meeting, organized as follows:

I. Summary of Projects Reviewed in FY 2010 AIGCC Peer Review:

A list of the 15 projects reviewed and the selection criteria

II. An Overview of the Evaluation Scores in FY 2010:

Average scores and a summary of evaluations, including analysis and recommendations

III. Summary of Key Project Findings:

An overview of key findings from project evaluations

IV. Process Considerations for Future Peer Reviews:

Lessons learned in this review that may be applied to future reviews

II. SUMMARY OF PROJECTS REVIEWED IN FY 2010 AIGCC PEER REVIEW

NETL selected key projects within the AIGCC program as well as related projects being conducted in NETL's Office of Research and Development (ORD) and Office of Systems Analysis and Planning (OSAP), and the Advanced Research Program to be reviewed by the independent Panel. Selected projects are listed below, with the name of the organization leading the research. A short summary of each of the above projects is presented in Appendix E.

PROJECTS REVIEWED

01: OSAP–GS-10F-0189T / DE-NT0005816
Coal Gasification Technology Pathways: Volume II—*Noblis*

02: DE-FC26-98FT40343
Development of ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems—*Air Products and Chemicals, Inc.*

03: DE-FE0000489
High Temperature Syngas Cleanup Technology Scale-Up and Demonstration Project—*Research Triangle Institute*

04: DE-FC26-05NT42459
Integrated Warm Gas Multicontaminant Cleanup Technologies for Coal-Derived Syngas—*Research Triangle Institute*

05: DE-FC26-05NT42458
Development of an Integrated Multicontaminant Removal Process Applied to Warm Syngas Cleanup for Coal-Based Advanced Gasification Systems—*Gas Technology Institute*

06: DE-FC26-05NT42469
Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants—*Eltron Research & Development, Inc.*

07: DE-FC26-04NT42237
Development of Technologies and Capabilities for Coal Energy Resources—*Pratt and Whitney Rocketdyne, Inc. (formerly The Boeing Company)*

08: DE-FC26-06NT42758
Co-Production of Electricity and Hydrogen Using a Novel Iron-Based Catalyst—*Research Triangle Institute*

09: DE-FC26-99FT40685
Single-Crystal Sapphire Optical Fiber Sensor Instrumentation—*Virginia Polytechnic Institute & State University*

10: OSAP–401.01.13
GHG Reductions in the Power Industry Using Domestic Coal and Biomass—*National Energy Technology Laboratory*

11: ORD-10-220615.1 / ORD-10-220663.9
Fuel Flexible Advanced Energy Systems for the Production of Syngas—*National Energy Technology Laboratory*

12: ORD-09-220677-T02
Dynamic Simulation and Control of Advanced Power Generation Systems—*National Energy Technology Laboratory*

13: DE-FC26-07NT43094
Development of Model Based Controls for GE's Gasifier and Syngas Cooler—*General Electric Global Research*

14: OSAP–401.01.14
Cost and Performance Baseline for Fossil Energy Plants - Volume 3: Low Rank Coal and Natural Gas to Electricity—*National Energy Technology Laboratory*

15: DE-NT0004397
Arrowhead Center to Promote Prosperity and Public Welfare in New Mexico—*New Mexico State University*

III. AN OVERVIEW OF THE EVALUATION SCORES FOR THE AIGCC PROGRAM

For each of the nine review criteria, an individual reviewer was asked to score the project as one of the following:

Effective (5)

Moderately Effective (4)

Adequate (3)

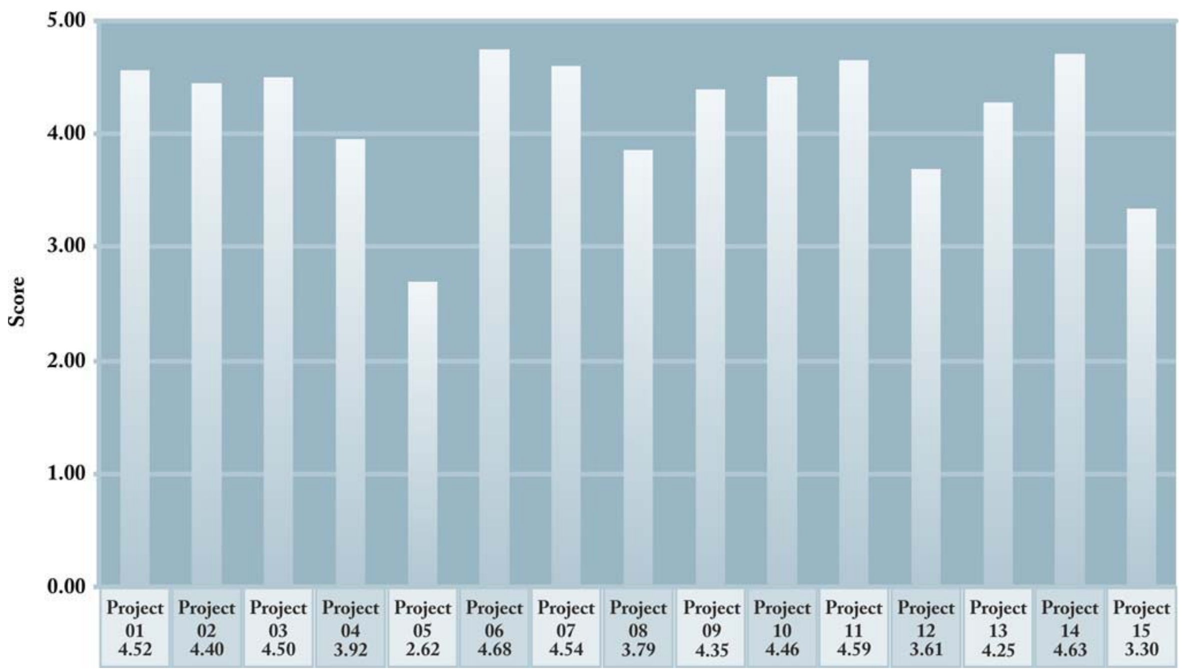
Ineffective (2)

Results Not Demonstrated (1)

The average scores for all the projects and across the rating criteria indicate that, overall, the AIGCC program is very strong. The program consists primarily of well-managed and well-staffed projects aimed at developing innovative and marketable technologies that have considerable potential to provide valuable benefits to the gasification industry.

Figure 1 shows the average project scores, representing the average of the nine review criteria, for each of the 15 projects reviewed. The Panel viewed most projects favorably: ten of the projects received an average project score above 4.0; four of the projects were scored between 3.0 and 4.0 (with two of those projects attaining near-4.0 scores); and only one project scored below 3.0. The project with the lowest average score earned a 2.6, while the project with the highest average score earned a 4.7. The average of the fifteen project scores was 4.1. These results indicate that the Panel deemed most projects moderately effective.

FIGURE 1 AVERAGE SCORING, BY PROJECT



General conclusions about the AIGCC program can also be drawn by looking at the average scores for each of the nine review criteria, which are shown in Table 1. Nearly all of the criteria received average scores of 4.0 or higher, reflecting the success of NETL and DOE in effectively leveraging government resources by funding well-managed projects that are developing innovative, economical, and scientifically rigorous technologies.

TABLE 1 AVERAGE SCORING, BY REVIEW CRITERION

Criterion	Project Average	Highest Project Average	Lowest Project Average
1. Scientific and Technical Merit	4.3	5.0	2.7
2. Existence of Clear, Measurable Milestones	4.2	5.0	2.6
3. Utilization of Government Resources	4.3	4.7	2.4
4. Technical Approach	4.2	4.7	2.4
5. Rate of Progress	4.1	5.0	2.6
6. Potential Technology Risks Considered	3.9	4.6	2.4
7. Performance and Economic Factors	4.0	5.0	2.6
8. Anticipated Benefits, if Successful	4.4	5.0	2.9
9. Technology Development Pathways	4.0	4.7	2.7

A copy of the Peer Review Criteria Form and a detailed explanation of the review process are provided in Appendix D.

IV. SUMMARY OF KEY FINDINGS

This section summarizes key findings from across the group of 15 individual projects that were evaluated.

General Project Strengths

The Panel found the majority of projects to be sound, applauding DOE for presenting a high-quality, diverse portfolio with great potential to contribute to the gasification industry. Only one project averaged a score below a rating of Adequate, while a full two-thirds of the portfolio averaged a score between the two top rankings of Moderately Effective and Effective. As seen in Table I, the Panel concluded that many of the projects provided great value for their level of funding and were of high scientific worth; the Panel was impressed by the quality of the projects as well as by their ambitious goals, and felt that most of the projects would have significant impact on the industry if they are completed successfully.

The Panel recognized that many of the projects had strong partnerships with respected industrial companies, which increases the potential for project success and the benefits that could be realized from this success, as the chances of commercialization and adoption are strengthened through these partnerships. In general, the Panel found project leadership and management of the projects impressive and most project teams experienced in and passionate about their areas of research.

The overall average score across all criteria of the 10 projects performing better than 4.0 (Projects 01, 02, 03, 06, 07, 09, 10, 11, 13, and 14) was 4.5. An average rating of 4.8 was given for Anticipated Benefits, if Successful across these 10 projects, demonstrating the considerable length NETL has gone to in order to ensure that its ambitious research and development (R&D) goals are achievable.

The projects conducted by NETL (Projects 10, 11, and 14), and the NETL-sponsored Systems Study by Noblis (Project 01) received overall average ratings of 4.5 or higher. This is reflective of the value that the Panel noted in systems studies and the quality of the work performed by NETL to execute these studies. These four projects continue NETL's outstanding benchmarking work and widely-accessed reports for existing and new technology implementation.

The highest-rated project was Project 06, "Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants," conducted by Eltron Research and Development. This project averaged 4.7 out of 5.0 across all criteria and earned a perfect 5.0 for the criteria Existence of Clear, Measurable Milestones and Anticipated Benefits, if Successful.

The Panel was also impressed by the portfolio's balance between laboratory experimentation and field development, noting that the greatest value is realized when a project progresses along the proper track, neither remaining too long in research without process test data/engineering scale-up data nor moving too quickly from applied research into a premature larger scale.

The Panel was particularly impressed by Projects 02, 03, 06, and 07 (earning overall average ratings of 4.4–4.7) and the progress made in each, with each project planning to move forward to large-scale field demonstrations in the 2010-plus time frame.

The Panel was pleased by the modeling efforts undertaken by many of the teams, which reflect a responsible, balanced use of funding to make experimentation more effective. Furthermore, the Panel considered the projects that seek to evaluate the projected impact of implemented technologies as having particularly high value because they provide NETL and stakeholders guidance to actively prepare and plan for future actions and investments.

General Project Weaknesses

The “Potential Technology Risks Considered” criterion had the lowest average score (3.9). This score is, objectively, a high score; however, just as several projects performed very well under this criterion, it also indicates that particular projects underperformed. Of these projects, the Panel found that several of these projects did not adequately identify and plan for the mitigation of factors that could lead to the failure of the project technology.

For Performance and Economic Factors, the average score of 4.0 indicates that, while the economic analyses provided had significantly improved in comparison to those provided in past peer reviews of R&D programs, several projects had not performed an adequate analysis of relevant economic factors or built a convincing case for the development of the technology. Similarly, the relatively lower rating for Technology Development Pathways stems, in part, from the Panel’s perception that some projects had not done sufficient analysis—particularly to demonstrate how the project technology could be incorporated into future IGCC systems.

Lastly, while many projects performed well in the Existence of Clear, Measurable Milestones criterion, the Panel noted that several milestones were simply repetitions of the task (i.e., “Perform the experiment”), rather than measurable performance metrics (i.e., “Achieve a specific result”). The Panel noted that such milestones enabled projects to advance to larger scales without fully considering the associated benefits and risks; similarly, such projects did not identify and ascertain all the potential information to be gained at a smaller scale prior to making the decision to move to a larger one.

Issues for Future Consideration

On the whole, the Panel was impressed by the technical expertise, knowledge, and ambition of the researchers. Most of the suggestions for improvement were technical in nature, specific to the particular project’s technology. However, one overarching issue emerged relating to the identification of risks: in general, the projects needed to tighten up their evaluation and discussion of project risks and focus this discussion more on the technology and commercial risks, not on the “soft risks” or funding issues into which the Panel cannot provide input. Additional recurring recommendations related to weakness in risk assessments included the recommendation of conducting additional economic cost/performance analyses and further detailing how a technology would be integrated with IGCC.

With regard to economic analysis, the Panel noted that, while focusing mostly on the technical aspects is common in R&D, several of the projects in the portfolio could significantly benefit from the development of additional sensitivity analyses for the technologies being developed.

The Panel also commented that several projects could be improved by strictly adhering to clear, performance-based success criteria that must be met before project work may advance. Examples included several laboratory-scale projects which would benefit from a more thorough investigation via modeling, and pilot-scale projects which require further laboratory-scale testing.

V. PROCESS CONSIDERATIONS FOR FUTURE PEER REVIEWS

The Panel and DOE/NETL managers involved in the Peer Review offered constructive comments on the review process and suggestions for future peer reviews. Comments were provided at the conclusion of the Peer Review Meeting. The following is a brief summary of ideas recommended for use in planning future project review sessions.

General Process Comments

All involved unanimously agreed that the current Peer Review process requires little or no modification to remain effective. There was high praise both for the facilitation of the meeting and the superb work of the support staff. Panel members found the computerized score tabulation method effective and beneficial, as it allowed for quick display of a project's preliminary average score. The Panel members greatly appreciated the adequate time they were given prior to the Peer Review Meeting to read through the project information documents and noted the efficiency gained from having a Sharepoint site available from which they could download all of the project documents. The Panel also recommends that all project folders and other content on the Sharepoint site be downloadable en masse, rather than forcing Panel members to download dozens of individual items. A macro downloading all files at once to designated folders on the user's computer would serve nicely.

The presentation and question-and-answer (Q&A) periods were held in closed sessions consisting only of DOE/NETL, ASME personnel and support contractors, the Panel, and the project PI's team, allowing for candid discussion of project-related material. However, several Panel members felt that certain aspects of projects avoided by the PIs due to sensitivity could have been presented without disclosing proprietary information.

In addition, the Panel thought it was important to inform each PI prior to the commencement of the Q&A period that the information exchanged during the Q&A period was understood to be confidential by the Panel, and that the Panel would not disclose any aspects of these discussions after the individual project discussions ended. This was done to allow the PI to be more open in their answers to all Panel questions, in order for the Panel to be able to provide the best assessment and guidance to the project.

The Panel found that nearly all projects were presented well, and that the presence of other project partners was very helpful in assisting the PI, when necessary, to respond the Panel's questions. The Panel was also pleased with the presenters' openness to recommendations, noting that they answered questions honestly without being defensive. It was also helpful to have the PI wait outside the meeting room during the Panel's internal discussions, because occasionally it was necessary to call the PI back to help clarify a particular point for the Panel.

The Panel asserted that a small number of the more developed projects would have benefited from an earlier expert review designed to assess and review project goals and planned activities.

Meeting Agenda

The Panel indicated that the meeting agenda was well structured, providing adequate time for presentations, questioning, and subsequent Panel discussion without feeling rushed or overburdened. In general, all the Panel was pleased with the time given to each aspect of the peer review process, and noted that allowing more time for the presentation and Q&A session for the more complex projects, rather than allotting equal time to all projects, was an improvement over prior peer reviews.

For this review meeting, the Panel applauded NETL for initiating the reviews with the Noblis Study (Project #1). Since the Noblis work did an excellent job of assessing the economic impact on IGCC cost and performance of many of the individual technologies that were on this agenda, it provided a useful platform to set the stage for the upcoming projects.

The diverse areas of expertise represented by the Panel members offered other members needed insight on various topics during discussion, providing more accurate and comprehensive ratings and comments.

Presentations

The Panel found that all projects benefited greatly from the presentation template provided by DOE, and greatly appreciated the efforts of DOE to familiarize the PIs with the presentation process.

However, the Panel found, in some cases, there to be an overabundance of administrative information. While the Panel acknowledged the necessity of such information, it suggested that the information in excess of the core project management-related information specifically required in presentation templates be made available specifically as background information and be excluded, for the greater part, from the actual presentation.

The Panel also recommended that the future templates include a slide in the early part of the presentation that outlines the scientific basis of the technology being evaluated. This would provide a useful context and enable Panel members with different backgrounds to more effectively evaluate the project.

A small number of presentations, however, suffered from unexplained or poorly presented information, requiring extensive questioning by the Panel to clarify. Recognizing that DOE has gone to great lengths to standardize project presentation, successfully implemented by the majority of projects, the Panel proposed that the basic template given the PIs be supplemented with examples to assist PIs in providing the proper information. The Panel also emphasized that the information presented should be as clear as possible, minimizing extraneous text, including acronyms and technical jargon.

The Panel also felt that time spent discussing portions of a project or a related project was confusing. It requested information on the boundaries of the technology being reviewed be made more explicit, particularly when it is a sub-project of a larger effort, and that the presentation include a flow diagram of where the technology fits into the entire process and how it relates to the overall output of the system.

Evaluations

The Panel noted that its introduction to and familiarization with the review process was accomplished quickly and effectively.

The scoring system was recognized as a prime motivator for discussion and was structured well overall; however, the Panel was somewhat uncomfortable rating a project according to its stated goals when the Panel found those goals to be questionable.

On a small number of occasions, the Panel found that input from the NETL Program Manager was necessary during the discussion period to clarify a broader programmatic issue related to the project being evaluated. The Panel appreciated that the Program Managers were available to offer assistance in these cases.

Review Panel

The Panel thanked DOE for the opportunity to participate in this Peer Review, citing it as an enjoyable and educational experience.

APPENDICES

APPENDIX A: ASME PEER REVIEW METHODOLOGY

The American Society of Mechanical Engineers (ASME) has been involved in conducting research since 1909 when it started work on steam boiler safety valves. Since then, the Society has expanded its research activities to a broad range of topics of interest to mechanical engineers. ASME draws on the impressive breadth and depth of technical knowledge among its members and, when necessary, experts from other disciplines for participation in ASME-related research programs. In 1985, ASME created the Center for Research and Technology Development (CRTD) to coordinate ASME's research programs.

As a result of the technical expertise of ASME's membership and its long commitment to supporting research programs, the Society has often been asked to provide independent, unbiased, and timely reviews of technical research by other organizations, including the federal government. After several years of experience in this area, the Society developed a standardized approach to reviewing research projects. This section provides a brief overview of the review procedure established for the U.S. Department of Energy (DOE)/National Energy Technology Laboratory (NETL) FY 2010 Advanced Integrated Gasification Combined Cycle Peer Review.

ASME Knowledge and Community Sector

One of the five sectors responsible for the activities of ASME's 127,000 members worldwide—the Knowledge and Community (K&C) Sector—is charged with disseminating technical information, providing forums for discussions to advance the mechanical engineering profession, and managing the Society's research activities.

Board on Research and Technology Development

ASME members with suitable industrial, academic, or governmental experience in the assessment of priorities for research and development, as well as in the identification of new or unfulfilled needs, are invited to serve on the Board on Research and Technology Development (BRTD) and to function as liaisons between BRTD and the appropriate ASME sectors, boards, and divisions. The BRTD has organized more than a dozen research committees in specific technical areas.

Center for Research and Technology Development

The mission of the Center for Research and Technology Development (CRTD) is to effectively plan and manage the collaborative research activities of ASME to meet the needs of the mechanical engineering profession as defined by the ASME members. The CRTD is governed by the BRTD, and day-to-day operations of the CRTD are handled by the director of research and his staff. The director of research serves as staff to the Peer Review Executive Committee, handles all logistical support for the Panel, provides facilitation of the actual review meeting, and prepares all summary documentation.

AIGCC Peer Review Executive Committee

For each set of projects to be reviewed, the BRTD convenes a Peer Review Executive Committee to oversee the review process. The Executive Committee is responsible for seeing that all ASME rules and procedures are followed; reviewing and approving the qualifications of those asked to sit on the Panel; ensuring that there are no conflicts of interest in the review process; and reviewing all documentation coming out of the project review. There must be at least three members of the Peer Review Executive Committee, and those members must have experience relevant to the program being reviewed. Members of the FY 2010 AIGCC Peer Review Executive Committee were as follows:

Richard T. Laudenat, Chair. Mr. Laudenat is the Senior Vice-President of the ASME Knowledge and Communities Sector. He was previously a Vice-President of the ASME Energy Conversion Group and was a member of the ASME Energy Committee.

William Stenzel, of Sargent & Lundy. Mr. Stenzel is a former chair of the ASME Power Division and past member of the ASME Energy Committee.

William Worek, of the University of Illinois. Dr. Worek is a past Vice-President of the ASME Energy Resources Group and former chair of the ASME Solar Energy Division. He currently serves on the ASME Mechanical Engineering Department Heads Committee.

AIGCC Peer Review Panel

The AIGCC Peer Review Executive Committee accepted résumés for proposed AIGCC Peer Review Panel members from CRTD, from a limited call to ASME members with relevant experience in this area, and from the DOE/NETL program staff. From these sources, the ASME Peer Review Executive Committee selected a seven-member review panel and agreed that they had the experience necessary to review the broad range of projects under this program and did not present any conflicts of interest. Panel members and qualifications are described in Appendix C.

Meeting Preparation and Logistics

Prior to the meeting, the project team for each project being reviewed was asked to submit an 11-page Project Information Form including project goals, purpose, accomplishments to date, etc. A standard set of specifications for preparing this document was provided by CRTD. These Project Information Forms were collected and provided to the Panel prior to the meeting.

Also in advance of the review meeting, CRTD gave the project teams a standard presentation format and set of instructions for the oral presentations they were to prepare for the Panel. All presentations were created in PowerPoint format; the Panel was also given hard-copy handouts of these slides.

The Project Information Forms and presentations for all projects were provided to the Panel well in advance of the meeting to help them to better prepare for their roles.

Project Presentations, Evaluations, and Discussion

At the AIGCC Peer Review Meeting, presenters were held to a specific time limit (ranging from 45 to 90 minutes) to allow sufficient time for all presentations within the five-day meeting period. After each presentation, the project team participated in a question-and-answer session with the Panel for 30 to 40 minutes.

The Panel then spent 40 minutes evaluating the projects based on the presentation material. To start, each reviewer scored the project against a set of predetermined peer review criteria. The following nine criteria were used:

- Scientific and Technical Merit
- Existence of Clear, Measurable Milestones
- Utilization of Government Resources
- Technical Approach
- Rate of Progress
- Potential Technology Risks Considered
- Performance and Economic Factors
- Anticipated Benefits if Successful
- Technology Development Pathways

For each of these review criteria, individual Panel members scored each project as one of the following:

- Effective (5)
- Moderately Effective (4)
- Adequate (3)
- Ineffective (2)
- Results Not Demonstrated (1)

To facilitate the evaluation process, TMS provided the Panel with laptop computers that were pre-loaded with Peer Review Criteria Forms for each project. After scoring the projects on these criteria, the Panel provided written comments about each project. The Panel then discussed the project for the purpose of defining project strengths, project weaknesses, recommendations for other possible activities, and a list of action items that the team must address.

APPENDIX B: MEETING AGENDA

U.S. Department of Energy - Office of Fossil Energy - National Energy Technology Laboratory

FY10 Advanced Integrated Gasification Combined Cycle (AIGCC) Peer Review

Pittsburgh Airport Marriott

December 7-11, 2009

AGENDA

MONDAY, DECEMBER 7, 2009 - SALON A&B

7:30 - 8:30 a.m.	Registration - **FOYER SALON A&B**
8:30 - 9:30 a.m.	Peer Review Panel Kick Off Meeting - Open to NETL and ASME staff only - Review of ASME Process - Michael Tinkleman/Ross Brindle, ASME - Role of Panel Chair - Daniel J. Kubek, ASME Peer Review Panel - Meeting logistics/completion of forms - Charles Schmidt/Nicole Ryan/Justin Strock, TMS - Role of NETL - José Figueroa, NETL
9:30 - 10:15 a.m.	Overview - Open to NETL and ASME staff only - AIGCC Technology Manager – Gary Stiegel, National Energy Technology Laboratory
10:15 - 10:30 a.m.	**BREAK - FOYER SALON A&B**
10:30 - 11:15 a.m.	***01 - Project # OSAP-GS-10F-0189T/DE-NT0005816*** - Coal Gasification Technology Pathways: Volume II - *David Gray*, **Noblis**
11:15 - 11:45 a.m.	Q&A
11:45 - 12:25 p.m.	Discussion, evaluation, and written comments
12:25 - 1:25 p.m.	**Lunch (on your own)**
1:25 - 2:55 p.m.	***02 - Project # FT40343*** - Development of ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems - *Phillip A. Armstrong*, **Air Products and Chemicals, Inc.**
2:55 - 3:35 p.m.	Q&A
3:35 - 4:15 p.m.	Discussion, evaluation, and written comments

TUESDAY, DECEMBER 8, 2009 - SALON A&B

7:00 - 8:00 a.m.	Registration - **FOYER SALON A&B**
8:00 - 9:15 a.m.	***03 - Project # FE0000489*** - High Temperature Syngas Cleanup Technology Scale-Up and Demonstration Project - *Raghubir Gupta*, **Research Triangle Institute**
9:15 - 9:55 a.m.	Q&A
9:55 - 10:35 a.m.	Discussion, evaluation, and written comments
10:35 - 10:50 a.m.	**BREAK - FOYER SALON A&B**

FY10 Advanced Integrated Gasification Combined Cycle (AIGCC) Peer Review

Pittsburgh Airport Marriott

December 7-11, 2009

TUESDAY, DECEMBER 8, 2009 - SALON A&B

10:50 - 11:35 a.m.	***04 - Project # NT42459*** - Integrated Warm Gas Multicontaminant Cleanup Technologies for Coal-Derived Syngas - *Brian S. Turk*, **Research Triangle Institute**
11:35 - 12:05 p.m.	Q&A
12:05 - 12:45 p.m.	Discussion, evaluation, and written comments
12:45 - 1:45 p.m.	**Lunch (on your own)**
1:45 - 2:30 p.m.	***05 - Project # NT42458*** - Development of an Integrated Multicontaminant Removal Process Applied to Warm Syngas Cleanup for Coal-Based Advanced Gasification Systems - *Howard S. Meyer*, **Gas Technology Institute**
2:30 - 3:00 p.m.	Q&A
3:00 - 3:40 p.m.	Discussion, evaluation, and written comments
3:40 - 3:55 p.m.	BREAK - FOYER SALON A&B
3:55 - 5:10 p.m.	***06 - Project # NT42469*** - Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants - *Douglas S. Jack*, **Eltron Research & Development, Inc.**
5:10 - 5:50 p.m.	Q&A
5:50 - 6:30 p.m.	Discussion, evaluation, and written comments

WEDNESDAY, DECEMBER 9, 2009 - SALON A&B

7:00 - 8:00 a.m.	Registration - FOYER SALON A&B
8:00 - 9:15 a.m.	***07 - Project # NT42237*** - Development of Technologies and Capabilities for Coal Energy Resources - *Timothy Saunders*, **Pratt and Whitney Rocketdyne, Inc.**
9:15 - 9:55 a.m.	Q&A
9:55 - 10:35 a.m.	Discussion, evaluation, and written comments
10:35 - 10:50 a.m.	BREAK - FOYER SALON A&B
10:50 - 11:35 a.m.	***08 - Project # NT42758*** - Co-Production of Electricity and Hydrogen Using a Novel Iron-Based Catalyst - *Jason P. Trembly*, **Research Triangle Institute**
11:35 - 12:05 p.m.	Q&A
12:05 - 12:45 p.m.	Discussion, evaluation, and written comments
12:45 - 1:45 p.m.	**Lunch (on your own)**
1:45 - 2:30 p.m.	***09 - Project # FT40685*** - Single-Crystal Sapphire Optical Fiber Sensor Instrumentation - *Anbo Wang*, **Virginia Polytechnic Institute & State University**
2:30 - 3:00 p.m.	Q&A
3:00 - 3:40 p.m.	Discussion, evaluation, and written comments

FY10 Advanced Integrated Gasification Combined Cycle (AIGCC) Peer Review

Pittsburgh Airport Marriott

December 7-11, 2009

WEDNESDAY, DECEMBER 9, 2009 - SALON A&B

3:40 - 3:55 p.m.	**BREAK - FOYER SALON A&B**
3:55 - 4:40 p.m.	***10 - Project # OSAP-401.01.13*** - GHG Reductions in the Power Industry Using Domestic Coal and Biomass - *Michael Matuszewski*, **National Energy Technology Laboratory**
4:40 - 5:10 p.m.	Q&A
5:10 - 5:50 p.m.	Discussion, evaluation, and written comments

THURSDAY, DECEMBER 10, 2009 - SALON A&B

7:00 - 8:00 a.m.	Registration - **FOYER SALON A&B**
8:00 - 8:45 a.m.	***11 - Project # ORD-10-220615.1 / ORD-10-220663.9*** - Fuel Flexible Advanced Energy Systems for the Production of Syngas - *Bryan Morreale* , **National Energy Technology Laboratory**
8:45 - 9:15 a.m.	Q&A
9:15 - 9:55 a.m.	Discussion, evaluation, and written comments
9:55 - 10:10 a.m.	**BREAK - FOYER SALON A&B**
10:10 - 11:25 a.m.	***12 - Project # ORD-09-220677-T02*** - Dynamic Simulation and Control of Advanced Power Generation Systems - *Stephen E. Zitney*, **National Energy Technology Laboratory**
11:25 - 12:05 p.m.	Q&A
12:05 - 12:45 p.m.	Discussion, evaluation, and written comments
12:45 - 1:45 p.m.	**Lunch (on your own)**
1:45 - 2:30 p.m.	***13 - Project # NT43094*** - Development of Model Based Controls for GE's Gasifier and Syngas Cooler - *Aditya Kumar*, **General Electric Global Research**
2:30 - 3:00 p.m.	Q&A
3:00 - 3:40 p.m.	Discussion, evaluation, and written comments
3:40 - 3:55 p.m.	**BREAK - FOYER SALON A&B**
3:55 - 4:40 p.m.	***14 - Project # OSAP-401.01.14*** - Cost and Performance Baseline for Fossil Energy Plants - Volume 3: Low Rank Coal and Natural Gas to Electricity - *Jeffrey Hoffmann*, **National Energy Technology Laboratory**
4:40 - 5:10 p.m.	Q&A
5:10 - 5:50 p.m.	Discussion, evaluation, and written comments

FRIDAY, DECEMBER 11, 2009 - SALON A&B

7:00 - 8:00 a.m.	Registration - **FOYER SALON A&B**

FY10 Advanced Integrated Gasification Combined Cycle (AIGCC) Peer Review

Pittsburgh Airport Marriott

December 7-11, 2009

FRIDAY, DECEMBER 11, 2009 - SALON A&B

8:00 - 8:45 a.m.	***15 - Project # NT04397*** - Arrowhead Center to Promote Prosperity and Public Welfare in New Mexico - *James T. Peach*, **New Mexico State University**
8:45 - 9:15 a.m.	Q&A
9:15 - 9:55 a.m.	Discussion, evaluation, and written comments
9:55 - 10:10 a.m.	**BREAK - FOYER SALON A&B**
10:10 - 12:00 p.m.	Overall meeting Wrap-up 10 minutes/Reviewers x 8

APPENDIX C: PEER REVIEW PANEL MEMBERS

After reviewing the scientific areas and issues addressed by the 15 projects to be reviewed, the CRTD staff and the ASME Peer Review Executive Committee, in cooperation with the NETL project manager, identified the following areas of expertise as the required skill sets that the FY 2010 AIGCC Peer Review Panel ("Panel") would need to possess:

- Membranes, Catalysts, Stability, and Sorbents
- Ceramic Materials and Ceramic Powders
- Commercialization Analysis
- High Temperature and High Pressure Processes
- Pollutant Identification, Monitoring, and Handling
- Computer Simulation and Modeling
- Module Design, Fabrication, and Bench Testing
- Biomass, Coal Characterization, and Petroleum Coke
- Cost & Economic Analysis
- Component Testing
- IGCC Design, Operation, and Controls
- Field Testing, Demonstrations, and Training
- Gasifiers, Novel Designs, and Absorption
- Syngas Clean-up and Multiple Contaminants

These required reviewer skill sets are then put into a matrix format and potential Panel members are evaluated in terms of their expertise to match the skill sets required. This matrix also ensures that all the necessary skill sets are covered by the Panel.

It was also important that the Panel represent the distinct perspectives of academia and industry.

Considering the areas of expertise listed above, the CRTD carefully reviewed the résumés of all those who had served on prior ASME Review Panels for DOE (acknowledging the benefit of their previous experience in this form of Peer Review Meeting), a number of new submissions from DOE, and those resulting from a limited call to ASME members with relevant experience. It was determined that three individuals who had served on prior ASME Review Panels were well-qualified to serve on the AIGCC Panel.

Appropriate résumés were then submitted to the AIGCC Peer Review Executive Committee for review. The following seven members were selected for the FY 2010 AIGCC Peer Review Panel (* indicates a prior Panel member):

Daniel J. Kubek*, Consultant—Panel Chair

Arie Geertsema, Consultant

Chris Higman, Consultant

Arnold Keller, Consultant

Ravi Prasad*, Consultant

James C. Sorensen*, Consultant

Ting Wang, University of New Orleans

Panel members reviewed pre-presentation materials prior to the meeting and spent five days at the meeting evaluating projects and providing comments. Panelists received an honorarium for their time as well as reimbursement of travel expenses. A brief summary of their qualifications follows.

FY 2010 AIGCC Peer Review Panel Members

Daniel Kubek – Panel Chair

Mr. Kubek is a consultant specializing in synthesis gas and natural gas purification and separation. His clients include the Electric Power Research Institute (EPRI) – CoalFleet, for whom he provides technical guidance on integrated processes for gasification projects; and the Gasification Technologies Council (GTC), where he serves as an advisor on technical issues related to gasification, particularly in the areas of hydrogen sulfide removal and carbon dioxide capture and sequestration. Prior to this, Mr. Kubek was with Universal Oil Products (UOP) for 18 years as senior technology manager. His primary work was for UOP’s solvent absorption, molecular sieve adsorption, and hydrogen processing technologies as applied to natural gas and synthesis gas processing. He was the process manager responsible for all process design packages for multiple gasification projects and served as development manager for their gas-processing business. In 2005, Mr. Kubek was awarded UOP’s Don Carlson Award for Career Technical Innovation. Before joining UOP, he spent 17 years with Union Carbide. Mr. Kubek received a B.S. degree in chemical engineering from Rutgers University and earned an M.S. in chemical engineering from Purdue University.

Arie Geertsema

Dr. Geertsema was formerly with Range Fuels, a start-up company which is erecting a thermochemical cellulosic ethanol plant in Georgia. Dr. Geertsema served as Chief Technical Officer responsible for technology development, intellectual property, and catalysis, and as Senior Vice President of Technology responsible for R&D and Engineering. Prior to joining Range Fuels, he was Director of the University of Kentucky’s Center for Applied Energy Research, where the main areas of activity were catalysis, carbon materials, and coal and environmental technologies. He spent two decades at Sasol in South Africa. Research fields included coal technology, gasification, gas processing and gas cleaning, Fischer-Tropsch, catalysis, petrochemical synthesis, separations technology, catalytic distillation, environmental research (air pollution, effluents, site remediation, etc.), biotechnology, fuel performance, process development, reactor design and development, piloting and commercialization of processes, and technoeconomic evaluations. Dr. Geertsema is a member of both the American Institute of Chemical Engineers (AIChE) and the American Chemical Society (ACS). He received B.S. and M.S. degrees in industrial chemistry, an M.B.A. from the Potchefstroom University South Africa, and a Dr-Ing (*German Engineering Doctorate Degree)* from the University of Karlsruhe, Germany.

Chris Higman

Mr. Higman is principal and owner of Higman Consulting GmbH based near Frankfurt, Germany which specializes in gasification and other syngas technologies. Mr. Higman performs pre-feasibility studies, plant audits, and runs training courses in gasification. Among his recent activities, he prepared a report for the Electric Power Research Institute (EPRI) on reliability and availability issues in operating IGCC power plants. Before retiring from Lurgi AG after 30 years service, Mr. Higman held numerous positions, serving as the head of the process division responsible for gasification technologies as well as Managing Director of Lurgi India. His work was mostly in the field of complete plans based on gasification and steam reforming including various ammonia, methanol, and syngas plants. Mr. Higman has a B.S. degree in mathematics from Oxford University and an M.S. in mechanical engineering from the University of the Witwatersrand in South Africa.

Arnold Keller, P.E.

Mr. Keller is a consultant with expertise in oil, gas, and coal processing; power and heat recovery projects (including cogeneration and combined cycles); and synergistic integration of process plant facilities with power cycles. Mr. Keller was previously a Technical Director/Process Engineer at Fluor Enterprises where he was responsible for several gasification design projects. Prior to that he was a Senior Process Engineer at ConocoPhillips (COP), where he was assigned to the E-Gas™ gasification group which was responsible for process design development for COP-owned E-Gas™ project developments. The design focus was on the CO-Shift, acid gas removal, Claus plant, methanation, and the integration of power within an E-Gas™ complex. Mr. Keller is a member of the American Institute of Chemical Engineers (AIChE), and the Institution of Chemical Engineers, (I.Chem.E), United Kingdom. He has a B.S. in chemical engineering from the University of Manchester Institute of Science & Technology in the United Kingdom.

Ravi Prasad, Ph.D.

Dr. Prasad of Helios-NRG, LLC has 60 U.S. patents and broad industrial experience in developing and commercializing new technologies, launching technology programs ($2–$50MM), supporting business development, building cross-functional teams, and setting up joint development alliances. Previously with Praxair Inc for 30 years as Corporate Fellow, Senior Development Associate, and other roles, he is a founding member of an alliance involving Praxair, British Petroleum, Amoco, Phillips Petroleum, Statoil, and Sasol to develop ceramic membrane syngas technology for gas-to-liquid processes. He established and led programs for ceramic membrane oxygen technology; co-developed proposals to secure major DOE programs worth $35MM in syngas and $20MM in oxygen; identified novel, solid-state oxygen generation technology; and conceived and implemented a coherent corporate strategy in nanotechnology. He has championed many initiatives in India, including small on-site hydrogen plants, small gasifiers, and aerospace business opportunities, and developed implementation plans resulting in a new R&D center in Shanghai. 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, New York.

James C. Sorensen

Mr. Sorensen is a consultant with a primary focus on clean coal and supporting technologies, including Integrated Gasification Combined Cycle (IGCC), Oxyfuel combustion, and Coal-To-Liquids. Prior to founding Sorensenergy, LLC, he worked for Air Products & Chemicals, including positions as Director, New Markets with responsibility for Syngas Conversion Technology Development and Government Systems; and Director, Gasification & Energy Conversion with responsibility for air separation plant sales for gasification applications. Prior responsibilities included project management of Air Products' baseload LNG projects, commercial management of SNG production, and general management of the Membrane Systems department. Mr. Sorensen is the founding chairman of the Gasification Technologies Council. He received a B.S. and an M.S. in chemical engineering from Caltech and Washington State University, respectively, and an M.B.A. from the Harvard Business School.

Ting Wang, Ph.D.

Dr. Wang is the Jack and Reba Matthey Endowed Chair for Energy Research and Director of the Energy Conversion and Conservation Center at the University of New Orleans. Dr. Wang has been involved in energy conservation and power generation for the past 29 years. He is an experimentalist with significant computational fluid dynamics experience. In the area of power generation, his specialties lie in gas turbine power generation with applications on combined power generation, co-generation, integrated gasification combined cycles (IGCC), mild gasification (MaGIC), distributed generation, and micro-turbine applications. He has conducted both fundamental and applied research with funding from U.S. government agencies and industry. Dr. Wang was the recipient of the ASME George Westinghouse Silver Medal for his contributions to the power industry. He is a member of the ASME Gas Turbine Heat Transfer Committee and the Chair of the Coal, Biomass, and Alternative Fuels Committee. Dr. Wang received an M.S. from the State University of New York at Buffalo and a Ph.D. from the University of Minnesota.

APPENDIX D: PEER REVIEW CRITERIA FORM

PEER REVIEW CRITERIA FORM

U. S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
FY10 ADVANCED INTEGRATED GASIFICATION COMBINED CYCLE (AIGCC) PEER REVIEW

December 7 – 11, 2009

Project Title:	
Performer:	
Presenter:	
Name of Peer Reviewer:	
Date of Review:	

The following pages contain the criteria used to evaluate each project. The criteria have been grouped into three (3) major categories: (1) **Approach and Progress**; (2) **Project Merit**; and (3) **Deployment Considerations**. Additionally, each criterion is accompanied by multiple characteristics to further define the topic.

The Reviewer is expected to provide a **rating** and **substantive comments** which support that rating for each criterion. Please note that if a rating of ***"Results Not Demonstrated"*** is selected, **justifying comments must be included**. To assist with determining the criterion rating, adjectival descriptions of those ratings are provided below.

RATING CRITERIA DEFINITIONS	
Effective	**Effective** projects set ambitious goals, achieve results, are well-managed and enhance the likelihood of meeting program goals and objectives.
Moderately Effective	In general, a project rated **Moderately Effective** has set ambitious goals and is well-managed, and is achieving results. Better results could be realized by focusing on key technical issues, more efficient use of resources, and improvements in overall management.
Adequate	**Adequate** describes a project that needs to set more ambitious goals, achieve better results, improve accountability or strengthen its management practices.
Ineffective	**Ineffective** projects are unable to achieve results due to a lack of clarity regarding the project's purpose or goals, poor management, or some other significant weakness (e.g., technical problem).
Results Not Demonstrated	**Results Not Demonstrated** indicates that a project has not been able to develop acceptable performance goals or collect data to determine whether it is performing.

Page 1 of 5

PEER REVIEW RATING CRITERIA

Please evaluate the project against each of the 9 criterion listed below. Definitions for these 9 criteria are provided on page 4. For each criterion, select the appropriate rating by typing an "X" in the applicable cell. Definitions for the five ratings criteria are provided on page 1.

NOTE: If you rate any criterion as "Results Not Demonstrated," a justification for this rating is required. Please include your justification in the box at the end of this table.

CRITERION		RATING CRITERIA				
(Criterion Definitions, refer to Page 4)		(Rating Criteria Definitions, refer to Page 1)				
		Effective	Moderately Effective	Adequate	Ineffective	Results Not Demonstrated*
PROJECT OVERVIEW						
1	**Scientific and Technical Merit**					
2	**Existence of Clear, Measurable Milestones**					
3	**Utilization of Government Resources**					
TECHNICAL DISCUSSION						
4	**Technical Approach**					
5	**Rate of Progress**					
6	**Potential Technology Risks Considered**					
7	**Performance and Economic Factors**					
TECHNOLOGY BENEFITS						
8	**Anticipated Benefits, if Successful**					
9	**Technology Development Pathways**					
*Please explain why the project was rated "Results Not Demonstrated" for a particular criterion.						

Page 2 of 5

COMMENTS

Please provide your comments for each of the areas in the blocks below. Please substantiate your comments (i.e., facts on why you are making the statement). General statements without explanation (e.g., great project) are not sufficient. Please avoid any use of clichés, colloquialisms or slang.

Strengths:
Weaknesses:
Recommendations:
Action Items:
General Comments:

Page 3 of 5

CRITERION DEFINITIONS

PROJECT OVERVIEW

1: Scientific and Technical Merit
- The underlying project concept is scientifically sound.
- Substantial progress or even a breakthrough is possible.
- A high degree of innovation is evident.

2: Existence of Clear, Measurable Milestones
- At least two measureable milestones per budget period exist.
- Milestones are quantitative and clearly show progression towards project goals.
- Each milestone has a title, planned completion date and a description of the method/process/measure used to verify completion.

3: Utilization of Government Resources
- Research team is adequate to address project goal and objectives.
- Sound rationale presented for teaming or collaborative efforts.
- Equipment, materials, and facilities are adequate to meet goals.

TECHNICAL DISCUSSION

4: Technical Approach
- Technical approach is sound and supports stated project goal and objectives.
- A thorough understanding of potential technical challenges and technical barriers is evident.

5: Rate of Progress
- Progress to date against stated project goal, objectives, milestones, and schedule is reasonable.
- Continued progress against possible technical barriers is likely.
- There is a high likelihood project goal, objectives, and expected outcomes and benefits will be achieved.
- The budget is on track to achieve project goal and objectives.

6: Potential Technology Risks Considered
- Potential risks to the environment or public associated with widespread technology deployment have been considered.
- Project risks are identified and effective measures to address and mitigate these risks, including potential technical uncertainties and barriers, are presented.
- Scientific risks are within reasonable limits.

7: Performance and Economic Factors *
- Appropriate technology cost and performance assessments are conducted consistent with the level of technology development.
- Implementation cost estimates, if warranted, are sensible given uncertainties.
- There is a high likelihood of meeting ultimate DOE cost and performance goals.

TECHNOLOGY BENEFITS

8: Anticipated Benefits, if Successful
- There exist clear statements of potential benefits if research is successful.
- Technologies being developed can benefit other programs.
- Project will make a significant contribution towards meeting near- and long-term program cost and performance goals.

9: Technology Development Pathways *
- Researchers know and can describe a "real world" application and adequately discuss requirements (additional research, potential partners, and resources) for the next level of technology development.
- Market analyses, if appropriate, indicate the technology being developed is likely to be implemented if research is successful.
- Potential barriers to commercialization have been identified and addressed, if appropriate.

* Additional details to be considered for Criterion 7 (Performance and Economic Factors) and 9 (Technology Development Pathways) for specific Technology Development Stages are described on the next page.

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TECHNOLOGY DEVELOPMENT STAGES FOR ECONOMIC ANALYSIS & TECHNOLOGY DEVELOPMENT PATH

In past Peer Reviews, Peer Review Panelists have had difficulty scoring the "Economic Analysis" and "Technology Development Path" criterions, because the rating criteria were not specific to the stage of technology development. Research, Development, and Demonstration projects can be categorized based on the level of technology maturity. Listed below are five (5) technology development categories of RD&D projects managed by the National Energy Technology Laboratory. These technology maturation categories are often termed "stages," which provide a basis for establishing a rational and structured approach to decision-making and identifying performance criteria that must be met before proceeding to a subsequent stage of development.

Fundamental Research—Explores and defines technical concepts or fundamental scientific knowledge; laboratory-scale; traditionally but not exclusively the province of academia.

Applied Research—Laboratory- or bench-scale proof of the feasibility of multiple potential applications of a given fundamental scientific discovery.

Prototype Testing—Prototype technology development and testing, either in the laboratory or field; predictive modeling or simulation of performance; evaluation of scalability.

Proof-of-Concept—Pilot-scale development and testing of technology or process; field testing and validation of technology at full-scale, but in a manner that is not designed or intended to represent a long-term commercial installation.

Major Demonstration—Commercial-scale demonstration of energy and energy-related environmental technologies; generally a first-of-a-kind representation of a long-term commercial installation.

Table 1 describes economic analysis and technology development sub-criteria for each of the five technology development stages. These sub-criteria are examples of the types of information that is typically determined in technology research and development projects.

Please note that the Economic Analysis and Technology Development Path are examples of the types of information that should be provided for the projects being reviewed. Projects are not expected to address all sub-criteria for a given Technology Development Stage, but should address at least one of them.

Table 1. Economic Analysis and Technology Development Sub-Criteria

Technology Development Stage	Economics Analysis Sub-Criteria	Technology Development Path Sub-Criteria
Fundamental Research	• Material costs available • Potential cost benefits over conventional systems identified	• Scientific feasibility proven • Application(s) considered • Potential technology developers identified
Applied Research	• Component or sub-system costs estimated • First-order cost-benefit analysis available • Material and energy balances calculated	• Conceptual process proposed • Potential applications well defined • Process feasibility established
Prototype Testing	• Conceptual process costs developed • Market analysis completed • Risk assessment completed	• Process test data available • Engineering scale-up data developed • Optimum operating conditions identified
Proof-of-Concept	• Process contingency costs identified • Full-scale process costs, including O&M calculated • Full-scale installation costs developed	• Major technology components thoroughly tested and evaluated • Technology demonstration plans firmly established • Major component optimization studies performed
Major Demonstration	• Installation costs determined	• Business and commercialization plans developed

APPENDIX E: AIGCC PROJECT SUMMARIES

Presentation ID Number	Project Number	Title
01	OSAP – GS-10F-0189T / DE-NT0005816	Coal Gasification Technology Pathways: Volume II
02	DE-FC26-98FT40343	Development of ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems
03	DE-FE0000489	High Temperature Syngas Cleanup Technology Scale-Up and Demonstration Project
04	DE-FC26-05NT42459	Integrated Warm Gas Multicontaminant Cleanup Technologies for Coal-Derived Syngas
05	DE-FC26-05NT42458	Development of an Integrated Multicontaminant Removal Process Applied to Warm Syngas Cleanup for Coal-Based Advanced Gasification Systems
06	DE-FC26-05NT42469	Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants
07	DE-FC26-04NT42237	Development of Technologies and Capabilities for Coal Energy Resources
08	DE-FC26-06NT42758	Co-Production of Electricity and Hydrogen Using a Novel Iron-Based Catalyst
09	DE-FC26-99FT40685	Single-Crystal Sapphire Optical Fiber Sensor Instrumentation
10	OSAP–401.01.13	GHG Reductions in the Power Industry Using Domestic Coal and Biomass
11	ORD-10-220615.1 / ORD-10-220663.9	Fuel Flexible Advanced Energy Systems for the Production of Syngas
12	ORD-09-220677-T02	Dynamic Simulation and Control of Advanced Power Generation Systems
13	DE-FC26-07NT43094	Development of Model Based Controls for GE's Gasifier and Syngas Cooler
14	OSAP–401.01.14	Cost and Performance Baseline for Fossil Energy Plants - Volume 3: Low Rank Coal and Natural Gas to Electricity
15	DE-NT04397	Arrowhead Center to Promote Prosperity and Public Welfare in New Mexico

01: OSAP-GS-10F-0189T/DE-NT0005816

Project Number OSAP-GS-10F-0189T/DE-NT0005816	**Project Title** Coal Gasification Technology Pathways: Volume II			
Contacts DOE/NETL Project Mgr.	**Name** Kristin Gerdes	**Organization** NETL – OSAP	**Email** Kristin.Gerdes@netl.doe.gov	
Principal Investigator	David Gray	Noblis	dgray@noblis.org	
Partners				
Stage of Development				
__ Fundamental	_X_ Applied R&D	__ Proof of Concept	__ Prototype Testing	__ Demonstration

Technical Background:

Over the next two decades, the United States will need to substantially increase power generation capacity. The possibility of more stringent environmental regulations for greenhouse gas emissions in the utility sector has opened a unique window of opportunity for integrated gasification combined cycle (IGCC) systems equipped with carbon capture and storage as a way to significantly contribute to this expansion. This project analyzed the performance and cost of an IGCC system when incorporating a series of advanced technologies under development in the DOE research and development (R&D) portfolio. These technologies have the potential to improve process efficiency, reduce capital and operating expense, and increase plant availability, resulting in a significant reduction in the cost of electricity (COE) for plants that capture carbon.

This project evaluated several advanced technologies within DOE's R&D program, including the following:

- Three models of advanced hydrogen turbines (AHTs)
- A dry coal feed pump
- Improved capacity factor
- Warm gas cleanup (WGCU)
- Hydrogen (H_2) membranes
- Coal synthesis gas (syngas) chemical looping (SCL)
- An ion transport membrane (ITM) for oxygen production
- A pressurized solid oxide fuel cell (SOFC) with a catalytic gasifier

This study is an extension of a previous Volume 1 report that investigated a pathway of advanced technologies under a non-carbon-capture scenario.

Relationship to Program:

This project will support important carbon capture and storage process advances through the engineering analyses pathway of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

The benefits of this project include the following:

- Creates a clear and quantitative link between the R&D portfolio and the program goals
- Shows the relative contribution of different R&D efforts within the Strategic Center for Coal portfolio

- Enables managers to defend program goals and show progress toward them by utilizing the analysis platform
- Identifies ancillary unit operations needed to enable advanced technologies and the symbiotic benefits of technologies within the DOE portfolio

The analysis shows that the cumulative impact of the portfolio of advanced technologies (assuming successful R&D) results in power plant configurations that are significantly more efficient and affordable than today's limited set of fossil energy technologies. The conceptual studies provided by this project highlight the importance of continued R&D, large-scale testing, and integrated deployment so that these technologies can be proven and become commercially accepted technologies for future coal-based power plants.

Table 1 summarizes the results of the analysis as each new technology is added to the pathway, highlighting the increase in efficiency and decrease in total plant cost (TPC) and 20-year levelized COE. The delta for each metric provides an estimate of the incremental benefits of the successful R&D of each technology. Turbine advancements contribute 50% of the efficiency improvement and 40% of the reduction in COE. The combined benefits of WGCU and the H_2 membrane or SCL contribute 40% of the efficiency benefit and 30% of the COE reduction. The remaining benefits are due to a combination of the coal feed pump, ITM, and research efforts to improve plant availability.

DOE's advanced power generation program goals are to achieve 90% carbon capture while maintaining less than a 10% increase in COE compared to a 2003 IGCC plant without carbon capture (9.30 ¢/kilowatt-hour [kWh] as determined by previous studies). DOE's cost target for carbon capture, at 10% above this value, is 10.23 ¢/kWh.

DOE's carbon capture target will be met early in the pathway, specifically by the case with an 85% capacity factor (CF). Other design features of that case include an advanced "F" hydrogen turbine, dry feed gasifier, cryogenic air separation unit, and cold gas cleanup. All subsequent technology advancements will help to exceed DOE's carbon capture targets. By achieving the ultimate, most advanced IGCC and integrated gasification fuel cell (IGFC) technologies projected in this study, DOE could realize a 20% reduction in COE over the 2003 reference IGCC plant without carbon capture.

CUMULATIVE COST AND PERFORMANCE IMPACT OF SUCCESSFUL R&D

Case No/Title	Efficiency (% HHV[1])	Total Plant Cost[2] ($/kW)	20–yr Levelized COE (¢/kWh)
Reference IGCC	30.4	2,718	11.48
Adv "F" Turbine	31.7	2,472	10.64
Coal Feed Pump	32.5	2,465	10.54
85% CF	32.5	2,465	10.14
WGCU/Selexol	33.3	2,425	10.00
SCL[3]	36.4	2,137	9.04
H_2 Membrane[3]	36.2	2,047	8.80
AHT–1 Turbine	38.0	1,855	8.14
ITM	38.3	1,724	7.74
AHT–2 Turbine	40.0	1,683	7.61
90% CF	40.0	1,683	7.36
IGCC Pathway			

[1] HHV stands for higher heating value.
[2] The TPC excludes the owner's costs.
[3] The SCL and H_2 membrane cases are alternate options for high-temperature carbon dioxide separation. The delta efficiency and costs are both relative to the WGCU/Selexol case. All subsequent cases incorporate the H_2 membrane.

Advanced Turbines

Advanced turbines contribute 4.8 percentage points to increased process efficiency due to the combination of (1) improved engine performance at increasingly higher firing temperatures, (2) air integration that reduces the auxiliary load of the main air compressor, and (3) increased turbine exit temperature, which improves heat recovery from the heat recovery steam generator, especially if an increase in steam superheat temperature is involved.

Advanced hydrogen turbines also significantly reduce TPC. Although the cost of the turbine itself increases due to increased size, TPC on a $/kW basis decreases because of increased net plant power. The advanced "F" turbine and the first-generation (AHT-1) turbine contribute significant COE reductions—a total of 15 mills/kWh. To maintain a nominal 600 MW plant size (the basis for this study), the second-generation (AHT-2) turbine case was reduced to a single process train. Due to the reverse economy of scale associated with this reduction from two process trains to a single process train, a minor decrease (1.3 mills/kWh) in COE occurs. In comparison, the COE decreases by 8.2 mills/kWh (an 11% reduction) if two trains are built.

Coal Feed Pump

The coal feed pump increases the gasifier cold gas efficiency by eliminating the need to evaporate water in a slurry-fed gasifier. This benefit is somewhat countered by a higher steam requirement for the water-gas shift reaction than was needed with a slurry feed. The resulting efficiency benefit is 0.8 percentage points. The minor change in the cost of equipment, coupled with a small reduction in net power associated with the coal feed pump, results in a negligible impact on TPC and COE.

Warm Gas Cleanup and Hydrogen Membrane / Syngas Chemical Looping

Warm gas cleanup (with Selexol CO_2 capture) improves process efficiency over cold gas cleanup in the carbon capture scenario by eliminating the sour water stripper reboiler duty. However, coupling warm gas cleanup with the H_2 membrane or SCL contributes an even greater increase in process efficiency by eliminating the Selexol regeneration steam requirements and auxiliary power and also by producing carbon dioxide (CO_2) at elevated pressure, which reduces the CO_2 compressor load.

The cost of warm gas desulfurization is projected to be less than that of single-stage Selexol, which partly accounts for the decrease in the TPC of the WGCU-plus-Selexol configuration. An even greater reduction in TPC occurs with the addition of an H_2 membrane or with SCL that replaces the second-stage Selexol absorber for CO_2 capture. Further, the cost of CO_2 compression is much less in the WGCU-plus-membrane or WGCU-plus-SCL case than in any of the previous carbon capture cases due to the higher pressure at which CO_2 is produced from the H_2 membrane and SCL. Finally, when the added net power generation (made possible by eliminating the sour water stripper and Selexol reboilers and reducing CO_2 compression parasitic losses) is divided into the already-reduced TPC, the cost of the WGCU-plus-membrane and WGCU-plus-SCL cases decreases by $418/kW and $328/kW, respectively, relative to the cold gas cleanup configuration. The COE benefit follows suit, decreasing by 13 mills/kWh and 11 mills/kWh, respectively.

Ion Transport Membrane

The ITM does not contribute strongly to process performance; its primary benefit is a decreased capital cost of oxygen production. The ITM is predicted to reduce TPC by $131/kW and the COE by 4 mills/kWh.

Reliability, Availability, and Maintainability

The effects of improved CF are as significant as the other technology improvements that yield increased process efficiency and decreased capital cost. Although increased CF does not influence either process efficiency or TPC, the added on-stream plant operation decreases COE by a total of 6.5 mills/kWh.

Pressurized Solid Oxide Fuel Cell

The pressurized SOFC case is capable of a process efficiency that approaches 60%. The catalytic gasifier, with high methane content in the syngas, operates with cold gas efficiency in excess of 90%. The conversion of chemical energy within the fuel cell, as opposed to thermal and mechanical energy conversion in an IGCC process, enables the higher process efficiency obtained in the IGFC case. Despite much higher process efficiency, the higher capital costs of the IGFC process relative to IGCC result in a TPC and COE that are slightly greater than the most advanced IGCC configuration with carbon capture. However, the SOFC case results in nearly 100% CO_2 removal, compared to the 90% capture rate of the IGCC.

The technology pathway evaluated in this study covers a time span of about 18 years of technology development. Results of the analysis clearly indicate the importance of continued R&D, large-scale testing, and integrated deployment so that future coal-based power plants will be capable of generating clean power with greater reliability and at significantly lower cost.

Aside from improved process efficiencies and reduced COE for power generation with carbon capture and without carbon capture, these advanced technologies enable the production of high-value products such as H_2, integration with SOFCs, and pre-combustion carbon capture projected at lower cost than post-combustion alternatives.

Primary Project Goal:

The goal of this project is to quantitatively evaluate potential process improvements and cost reductions resulting from successful R&D of advanced technologies for an IGCC with pre-combustion carbon capture. The analysis places individual technologies in the context of overall system performance. Results of the study will help DOE to prioritize the R&D effort, evaluate the value of individual project cost and performance targets in the context of overall system performance and cost, and validate the performance and cost goals for the R&D program by showing the cumulative effects of the R&D portfolio.

Objectives:

The primary project objective is to provide systems studies that assess the performance and COE impact of advanced technologies funded under DOE's R&D program. Each technology will be assessed in a consistent manner. At the same time, the process will take full advantage of the performance aspect of new unit operations and develop creative approaches to characterizing and modeling novel and conceptual technologies.

02: DE-FC26-98FT40343

Project Number	Project Title			
DE-FC26-98FT40343	Development of ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems			
Contacts	**Name**	**Organization**	**Email**	
DOE/NETL Project Mgr.	Arun C. Bose	NETL - Gasification Division	arun.bose@netl.doe.gov	
Principal Investigator	Douglas L. Bennett	Air Products and Chemicals, Inc.	bennetdl@airproducts.com	
Partners	Ceramatec, Inc.; The Pennsylvania State University; Concepts NREC; Electric Power Research Institute; Siemens; Becht Engineering; Williams International, LLC; Eltron Research; SOFCo EFS (formerly McDermott Technology); NovelEdge Technologies, LLC; GE Energy Gasification (formerly ChevronTexaco Gasification)			
Stage of Development				
__ Fundamental R&D	__ Applied R&D	__ Proof of Concept	_X_ Prototype Testing	__ Demonstration

Technical Background:

Modern cryogenic distillation for oxygen production is a mature technology. Air separation plants are now some of the most efficient distillation-based separation units available. However, because the overall thermodynamic efficiency of modern cryogenic air separation units approaches its theoretical limit, few significant breakthroughs are expected that would lead to a step-change reduction in the cost of producing oxygen. Two alternative technologies, adsorption and polymeric membrane separations, are limited in practice. The efficiency limitations inherent in adsorption restricts its application to relatively small plants (<150 tons per day [TPD] oxygen production), while polymeric membrane separations do not provide the separation factor and flux required for economical, large-scale oxygen production.

Recognizing the potential for membrane technology to impact oxygen cost, Air Products has identified a class of ceramic materials with high flux and selectivity characteristics that can form the basis for cost-efficient membranes. Ion transport membranes (ITMs) are fabricated from nonporous, multicomponent, metallic oxides that operate at high temperatures and have exceptionally high oxygen flux and selectivity. The materials were chosen from the class of oxide ceramics known as perovskites, which lose oxygen from their crystal structure with increasing temperature, forming vacancies in the oxygen sublattice. Oxygen can be transported through such materials by “hopping” from vacancy site to vacancy site. Because the ceramic is an oxide, only oxygen ions can occupy the vacancy sites; all other species, such as nitrogen, argon, or other constituents of air, are thermodynamically excluded. The oxygen in air is ionized on the surface of the ceramic ITM and diffuses through the membrane as oxygen ions, forming oxygen molecules on the other side. Thus, ITM oxygen-mixed conductors can separate oxygen from oxygen-containing gases with essentially complete selectivity and without an external electrical circuit. A simple oxygen anion gradient is all that is required to drive oxygen flow across the membrane material. This gradient can be set up by creating a partial pressure difference in oxygen on opposite sides of a membrane.

The resulting air separation system produces not only pure oxygen, but also a hot, pressurized, oxygen-depleted stream from which significant amounts of energy can be extracted. Significant reductions in the capital and operating costs of oxygen production are predicted. This potential for efficiently coproducing oxygen and power at reduced cost fits the goals of DOE's Advanced Power Systems Program.

Phase I of the program, which focused on the technical feasibility of the approach, was completed in 2001. Phase I focused on materials and the development and testing of a ceramic membrane wafer architecture. A perovskite material was chosen as the basis for further scale-up. The material has a combination of properties sufficient to meet commercial requirements for performance and operating life, including high oxygen flux, good material strength at high temperature, and resistance to system contaminants such as sulfur. In addition, the material is amenable to standard ceramic processing techniques that facilitate the design and manufacturing of multilayer, planar wafer structures. A planar architecture was chosen to help maximize the surface area in a separation device.

The wafer consists of two thin outer membrane layers through which the oxygen ions diffuse. The thin layers on the top and bottom of the wafer are supported by a porous layer, which is itself supported by a slotted layer. Hot, high-pressure air flows over the exterior of the membrane surface to the wafer. Oxygen passes from the air outside each wafer, through the thin outer membrane layer, through the pores of the porous layer, and into the slots of the innermost layer. Oxygen is collected at the center of each wafer. In a typical membrane module, stacks of wafers are joined together, separated by a spacer ring to form a gap for airflow between the wafers. The oxygen is collected in a central region of the module formed by the open center of each wafer and the spacer rings, and it passes out of the module through a ceramic tube sealed to a metal pipe. The high-pressure air on both sides of each wafer creates compressive stresses within the ceramic that stabilize the wafer. The planar design also makes the separation device very compact while facilitating good gas-phase mass transfer. All of the layers are made of the same ceramic material and therefore expand and contract together during temperature changes.

The planar wafers were scaled to their full commercial dimensions and produced in volume on a pilot production line using standard ceramic tape-casting technology. The production activities established the feasibility of achieving low-cost production, which is required to meet overall economic targets.

In Phase II, commercial-scale modules capable of producing up to 0.5 TPD of oxygen were built by conjoining multiple wafers to form a unified ceramic ITM oxygen separation vessel. The multi-wafer modules are arranged in a common flow duct and connected through a series of manifolds to an oxygen header below. The parallel and series arrangement of many of the modules meets the production requirements of a large tonnage oxygen plant. The modules are also fitted with a terminating end cap and ceramic pipe. The entire device, including the joints, is composed of the same ceramic, thus minimizing the potential for differential stresses caused by nonuniform expansion across the body of the device. Each commercial-scale module produces about 1 TPD of oxygen.

Phase II tasks culminated in the design, construction, and commissioning of a 5 TPD subscale engineering prototype (SEP) facility, which produced tonnage-quantity oxygen exceeding 95% purity. The SEP was designed to provide engineering scale-up data on arrays of commercial-scale modules.

The SEP was designed, constructed, and commissioned in Sparrows Point, Maryland during the final portion of Phase II. This unit features a prototype ITM pressure vessel, which holds six commercial-scale modules in a 2 by 3 array. Each module has a dedicated permeate train with vacuum pump and controller, and flow and purity measurement. The SEP is located adjacent to a commercial cryogenic gas air separation plant and is deployed in a recycle loop configuration, taking makeup gases from the commercial plant and recycling and recompressing its own off-gas as the balance of the feed. The feed stream to the membranes is first heated by recuperative heat exchange with the non-permeate stream, then brought to final temperature by an induction heater. Nominal membrane operating conditions for the unit are 800°C–900°C, 200 pounds per square inch gauge (psig) feed pressure, and <1 atmosphere permeate pressure. The SEP is equipped with sufficient flow capability to simulate the feed gas velocities anticipated in commercial service.

Relationship to Program:

This project will support important ITM advances through the gas separation pathway of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program. The ITM oxygen production technology is a radically different approach to producing low-cost, high-quality tonnage oxygen that will enhance the performance of integrated gasification combined cycle (IGCC) systems producing coal-derived synthesis gas (a mixture of hydrogen and carbon monoxide), which can be burned in a combustion turbine or used to produce clean transportation fuels and hydrogen fuel. System studies confirm the ITM benefits on IGCC systems, including a reduction of the IGCC plant-specific cost (expressed in dollars per kilowatt [$/kW]) by 9%, with a net power megawatt electric increase of 15%, a plant efficiency increase of 1.2%, and more than 25% savings ($/TPD) in oxygen production costs. Studies have indicated the potential for the use of ITM oxygen in other applications, such as oxygen-enriched combustion of coal and full oxycombustion. Other oxygen-intensive industries such as steel, glass, nonferrous metallurgy, refineries, and pulp and paper would realize cost, environmental, and productivity benefits as a result of the success of the ITM oxygen project.

Primary Project Goal:

The primary goal of the ITM oxygen project is to develop and scale up a novel, noncryogenic air separation technology with lower capital costs and energy requirements than conventional cryogenic processes. The technology will produce high-temperature/high-purity oxygen that is synergistic with IGCC systems and other advanced power generation technologies

Objectives:

Phase I objectives, now completed, focused on materials and process research and development and the design, construction, and operation of an approximately 0.1 TPD technology development unit (TDU). The TDU test data enabled the establishment of cost and performance targets for standalone, tonnage-quantity, commercial ITM oxygen plants and schemes for integrating ITM oxygen with IGCC and other advanced power generation systems.

Phase II activities were focused on testing the performance of full-size ITM oxygen modules in a 5 TPD SEP facility specially designed for this purpose. During Phase II, the team fabricated thin, cost-optimized multilayer ITM devices. These devices achieved oxygen production rates that exceeded commercial performance targets at anticipated commercial operating conditions with significant engineering lifetimes. The ITM oxygen modules were scaled up to commercial size, built, and tested during Phase II. Tests in the SEP generated information on the process for the current Phase III activity.

The objectives of Phase III are to increase the scale of the engineering test facility from 5 TPD to approximately 100–150 TPD of oxygen in an intermediate-scale test unit (ISTU). The ISTU features oxygen production from an ITM coupled with turbo machinery for power coproduction, and will provide data for further scale-up and development. In addition, and to support a larger test facility, expanded efforts in the areas of materials development, engineering development, ceramic processing development, and component testing are being undertaken.

03: DE-FE0000489

Project Number	**Project Title**			
DE-FE0000489	High Temperature Syngas Cleanup Technology Scale-Up and Demonstration Project			
Contacts	**Name**	**Organization**	**Email**	
DOE/NETL Project Mgr.	Jenny B. Tennant	NETL - Gasification Division	jenny.tennant@netl.doe.gov	
Principal Investigator	Raghubir Gupta	Research Triangle Institute	gupta@rti.org	
Partners	Tampa Electric Company (TECO) Engineering Company (to be determined)			
Stage of Development				
__ Fundamental R&D	__ Applied R&D	__ Proof of Concept	X Prototype Testing	__ Demonstration

Technical Background:

The gasification of coal or other carbonaceous feedstocks to produce coal synthesis gas (syngas) for power generation and fuel and chemical production has gained significant interest in recent years. However, to fully exploit the potential of gasification for coal and other feedstocks, such as petroleum coke (petcoke), high thermal and chemical efficiencies at competitive costs are a must. Because coal and petcoke gasification generates a syngas with a significant amount of contaminants (sulfur compounds, hydrochloric acid, ammonia, and heavy metals such as mercury [Hg], arsenic [As], and selenium [Se]), efficient syngas cleaning technologies will be key enablers for gasification's further deployment into the power and chemical sectors.

Even conventional contaminant removal technologies, such as the Selexol or Rectisol processes, struggle with new syngas cleaning specifications and requirements. Optimizing thermal efficiency to maximize cost competitiveness is challenging for these conventional technologies, which require substantial cooling of the syngas. Further, conventional technologies must add additional equipment to meet new syngas cleanup specifications for greater control of trace contaminants, resulting in increased process costs. Since social and political powers began to demand that carbon dioxide (CO_2) removal be part of the syngas cleaning process, the objective of maximizing thermal and chemical efficiencies at competitive costs has become even more important.

For the last 20 years, with DOE/NETL support, RTI International (RTI) has been developing various technologies for the efficient and cost-effective removal of contaminants from syngas at elevated temperatures(>400°F). These technologies can remove reduced sulfur species (hydrogen sulfide [H_2S] and carbonyl sulfide [COS]); heavy metals (Hg, As, and Se); hydrochloric acid; ammonia (NH_3); hydrogen cyanide (HCN); and CO_2 at these temperatures. They form the foundation of RTI's warm syngas cleanup platform. The modular nature of these technologies provides the flexibility to produce syngas that is suitable for either power or chemical production applications with the most cost-competitive syngas cleanup process.

One of the key highlights of RTI's research and development (R&D) program for the syngas cleanup technologies was a field test completed with real coal-derived syngas at Eastman Chemical Company's Coal to Chemicals facility in Kingsport, Tennessee. RTI's desulfurization technology was successfully demonstrated at a

0.3 megawatt electric (MWe) pilot plant using coal-derived syngas. Over more than 3,000 hours of operation, sulfur removal efficiencies of greater than 99.9% were achieved. Also during this pilot plant test, parametric testing demonstrated the process's robustness over a wide range of operating conditions, including the integrated operation of RTI's direct sulfur recovery process (DSRP) for converting the sulfur dioxide from sorbent regeneration into an elemental sulfur byproduct. Additional slipstream testing of other contaminant cleaning technologies at the Eastman facility also demonstrated Hg, As, NH_3, and HCN removal at elevated syngas temperatures.

The second highlight of RTI's R&D effort was an independent study by Nexant. The study concluded that warm syngas cleanup, when used for power generation in an integrated gasification combined cycle (IGCC) process scheme, can achieve an overall thermal efficiency gain of 3.6% higher heating value at a reduced capital cost in comparison to a Selexol-based cleanup process. This thermal efficiency gain represents about a 10% increase in an IGCC plant's net power output. In addition to the thermal efficiency gain, the warm syngas cleanup technology also reduced the capital cost of an IGCC plant by more than 5%, reducing capital requirements by about 14% per kW of power generation capacity. A second independent technoeconomic analysis by Noblis, supported by DOE/NETL, confirmed Nexant's general results. Overall, the warm syngas cleanup technology was shown to have key advantages for enabling IGCC and facilitating market penetration.

In 2007, RTI's R&D project for the warm syngas cleanup technologies was included in the Advanced Power Systems Peer Review. Overall, the Peer Review feedback was very positive about the R&D program's strengths and accomplishments. However, the Peer Review did recognize that all the technologies in RTI's warm syngas cleanup technology portfolio were not at the same stage of development. The final hurdle separating the sulfur technologies, including the high-temperature desulfurization process (HTDP) and DSRP, from commercial deployment was a large-scale demonstration. By contrast, some of the other technologies, primarily the regenerable high-temperature CO_2 sorbents, were still being tested at the laboratory scale.

To fulfill one of the recommendations from the 2007 Advanced Power Systems Peer Review, RTI and DOE signed a cooperative agreement in July 2009 to design, build, and test the more advanced technologies of RTI's warm syngas cleanup platform at the demonstration scale. The demonstration-scale system is expected to process the equivalent of 50 MWe, or about 2 million (MM) standard cubic feet per hour (scfh) (dry basis) of syngas, and will be operated at the Tampa Electric Company (TECO) 250 MWe IGCC plant at Polk Power Station near Tampa, Florida. To demonstrate RTI's warm syngas cleaning technologies at commercial operating conditions, the system will consist primarily of the following four test units:

- High-temperature desulfurization process (HTDP): This unit will process syngas flow equivalent to about 50 MWe (about 2 MM scfh of syngas on a dry basis) and produce a desulfurized syngas with a total sulfur (H_2S+COS) concentration < 5 parts per million by volume (ppmv).
- Trace contaminant removal process: This unit will remove trace contaminants (at least Hg, As, and Se) from a desulfurized syngas slipstream of about 200,000 scfh, corresponding to about 5 MWe of power equivalent.

- Direct sulfur recovery process (DSRP): This unit will be integrated with HTDP to process a slipstream of the regeneration off-gas from the HTDP to produce about 5 ton/day of sulfur.
- Warm CO_2 removal process: This unit will remove the CO_2 from a syngas slipstream of about 20,000 scfh, corresponding to about 0.5 MW of power equivalent.

The inclusion of the DSRP in this demonstration testing fulfills a second recommendation of the 2007 Advanced Power Systems Peer Review: to accelerate demonstration of the DSRP technology. This DSRP system's scale was selected to permit the use of standard commercial steam-traced sulfur collection equipment. However, the DSRP was not sized to match the HTDP system, because TECO converts the sulfur removed from the syngas into sulfuric acid, and the sulfur generated by DSRP reduces TECO's sulfuric acid production and the revenue from its sale.

Relationship to Program:

This project will support advances in the scale-up of high-temperature syngas cleanup technology within the gas cleaning focus area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

Results from the technoeconomic studies described in the previous section demonstrate that commercial deployment of the warm syngas cleanup technologies could result in both significant thermal efficiency improvements and capital cost improvements. However, the main challenge at hand is that the scale-up factor from the field testing at the 0.3 MWe Eastman facility to a full commercial unit for a 600 MWe IGCC plant would be about 2,000. This magnitude of scale-up required represents far too large a risk to attract funding for commercial deployment.

This project's key goal is to reduce the scale-up risk for subsequent commercial deployment to an acceptable level through a 50 MWe demonstration. In addition to reducing the scale-up risk, the current demonstration project will also provide the opportunity to develop commercially meaningful information about reliability, availability, and maintenance (RAM), demonstrate start-up and shutdown procedures for a commercial system, and accumulate operating experience under realistic industrial conditions.

Primary Project Goal:

The primary goal of this project is to mitigate the technical risks associated with the scale-up of RTI's warm syngas cleaning and CO_2 capture technologies, enabling subsequent commercial deployment.

Objectives:

The project has been divided into three budget periods to accomplish the primary project goal. The objectives for the first budget period of this project are to complete the necessary environmental permitting process; meet local, state, and DOE requirements; and complete a front-end engineering design (FEED) package. In the second phase of this project, detailed engineering, construction, commissioning, and operation will be completed at TECO's 250 MWe commercial coal gasification-based Polk Power Station located near Tampa, Florida.
During the second budget period, the specific project objectives are as follows:

1. Complete 5,000 hours of operation for all of the warm syngas cleaning technologies at commercial operating conditions.
   1.1 Demonstrate continuous operation of the HTDP system, processing a syngas flow equivalent to about 50 MW of power and producing a desulfurized syngas with a total sulfur concentration (H_2S + COS) < 5 ppmv.
   1.2 Demonstrate high-temperature removal of trace contaminants (at least Hg, As, and Se) with a syngas slipstream having a flow rate of approximately 200,000 scfh, corresponding to about 5 MW of power equivalent.
   1.3 Demonstrate the performance of the DSRP integrated with HTDP to process regeneration off-gas from the HTDP equivalent to about 5 tons/day of sulfur. This corresponds to handling about 13 MW equivalent of syngas (approximately 25% of the HTDP stream).
2. Establish RAM targets for a full-scale commercial system.
3. Establish operating experience that will enable start-up/shutdown, system turndown, and operator training for a commercial system.
4. Mitigate the design risk for a commercial plant by obtaining adequate design data from operation of the demonstration plant.

For the third budget period, the project objective is to conduct a pilot plant test at TECO of a warm syngas CO_2 removal process based on a regenerable CO_2 sorbent with a slipstream of about 20,000 scfh syngas, corresponding to about 0.5 MW of power equivalent.

Currently, the project is at the beginning of Phase1. The following table summarizes the work performed during Phase1, starting July 20, 2009 and ending September 30, 2009.

PROJECT ACCOMPLISHMENTS

Date	Achievements
Aug. 21, 2009	Sent initial announcement to seven engineering firms to solicit their intent to submit proposals for the preparation of the FEED package.
Sept. 3, 2009	Held project kickoff meeting at TECO's Polk Power Station near Tampa, FL. The meeting was attended by representatives from RTI, DOE, and TEC.
Sept. 4, 2009	Executed nondisclosure agreements between RTI and the seven bidding engineering firms.
Sept. 18, 2009	Issued a request for proposal (RFP) package to all seven engineering firms.

The proposals from the engineering firms were due by November 6, 2009. The team is well-positioned to complete the next major task of selecting an engineering firm to prepare the FEED package by the end of December 2009.

04: DE-FC26-05NT42459

Project Number DE-FC26-05NT42459	**Project Title** Integrated Warm Gas Multicontaminant Cleanup Technologies for Coal-Derived Syngas			
Contacts DOE/NETL Project Mgr.	**Name** Jenny B. Tennant	**Organization** NETL - Gasification Division	**Email** jenny.tennant@netl.doe.gov	
Principal Investigator	Brian Turk	Research Triangle Institute	bst@rti.org	
Partners	Nexant			
Stage of Development				
__ Fundamental	__ Applied	__ Proof of Concept	X Prototype Testing	__ Demonstration

Technical Background:

The gasification of coal or other carbonaceous feedstocks to produce coal synthesis gas (syngas) for power generation and fuel and chemical production has gained significant interest in recent years. However, to fully exploit the potential of gasification for coal and other feedstocks, such as petroleum coke (petcoke), high thermal and chemical efficiencies at competitive costs are a must. Because coal and petcoke gasification generate a syngas with a significant amount of contaminants (sulfur compounds, hydrogen chloride, ammonia, and heavy metals such as mercury, arsenic, and selenium), efficient syngas cleaning technologies will be key enablers for gasification's further deployment into the power and chemical sectors.

Even conventional contaminant removal technologies, such as the Selexol or Rectisol processes, struggle with new syngas cleaning specifications and requirements. Optimizing thermal efficiency to maximize cost competitiveness is challenging for these conventional technologies, which require substantial cooling of the syngas. Further, conventional technologies must add additional equipment to meet new syngas cleanup specifications for greater control of trace contaminants, resulting in increased process costs. Since social and political powers began to demand that carbon dioxide (CO_2) removal be part of the syngas cleaning process, the objective of maximizing thermal and chemical efficiencies at competitive costs has become even more important.

For the last 20 years, with DOE/NETL support, RTI International (RTI) has been developing various technologies for the efficient and cost-effective removal of contaminants from syngas at elevated temperatures (>400°F). These technologies can remove reduced sulfur species (hydrogen sulfide [H_2S] and carbonyl sulfide); heavy metals (mercury [Hg], arsenic [As], and selenium [Se]); hydrochloric acid (HCl); ammonia (NH_3); hydrogen cyanide (HCN); and CO_2 at these temperatures. They form the foundation of RTI's warm syngas cleanup platform. The modular nature of these technologies provides the flexibility to produce syngas suitable for either power or chemical production applications with the most cost-competitive syngas cleanup process.

One of the key highlights of RTI's research and development (R&D) program for the syngas cleanup technologies was a field test completed with real coal-derived syngas at Eastman Chemical Company's Coal to Chemicals facility in Kingsport, Tennessee. RTI's desulfurization technology was successfully demonstrated at a 0.3 megawatt electric (MWe) pilot plant using coal-derived syngas. With more than 3,000 hours of operation, sulfur removal efficiencies of greater than 99.9% were achieved. Also during this pilot plant test, parametric testing demonstrated the process's robustness over a wide range of operating conditions, including the integrated operation of RTI's direct sulfur recovery process (DSRP) for converting the sulfur dioxide from sorbent regeneration into an elemental sulfur byproduct. Additional slipstream testing of other contaminant cleaning technologies at the Eastman facility also demonstrated Hg, As, NH_3, and HCN removal at elevated syngas temperatures.

The second highlight of RTI's R&D effort was an independent study by Nexant. The study concluded that warm syngas cleanup, when used for power generation in an integrated gasification combined cycle (IGCC) process scheme, can achieve an overall thermal efficiency gain of 3.6% higher heating value at a reduced capital cost in comparison to a Selexol-based cleanup process. This thermal efficiency gain represents about a 10% increase in an IGCC plant's net power output. In addition to the thermal efficiency gain, the warm syngas cleanup technology also reduced the capital cost of an IGCC plant by more than 5%, reducing capital requirements by about 14% per kW of power generation capacity. A second independent technoeconomic analysis by Noblis, supported by DOE/NETL, confirmed Nexant's general results. Overall, the warm syngas cleanup technology was shown to have key advantages for enabling IGCC and facilitating market penetration.

Three events from the 2007 time frame significantly affected this project's subsequent development. First, Phase1 of this project was completed: the feasibility of an integrated warm syngas cleanup—including not only sulfur, but also NH_3, HCl, As, Hg, and Se—was demonstrated. Also in 2007, RTI's R&D project for the warm syngas cleanup technologies was included in the Advanced Power Systems Peer Review. Overall, the Peer Review feedback was very positive about the R&D program's strengths and accomplishments. However, the Peer Review also recognized that all of the technologies in RTI's warm syngas cleanup technology portfolio were not at the same stage of development. The final hurdle separating the sulfur technologies (including the high-temperature desulfurization process [HTDP] and DSRP) from commercial deployment was a large-scale demonstration. By contrast, some of the other technologies, primarily the regenerable high-temperature CO_2 sorbents, were still being tested at the laboratory scale. Third, in the same time period, the industrial partner with the ability to host the larger pilot plant testing withdrew from the project due to changed business objectives.

Phase 1's completion, the Advanced Power Systems Peer Review feedback, and the partner's withdrawal laid the groundwork for restructuring the project's second phase. The second phase originally had focused on combining laboratory- and pilot-scale testing to integrate and intensify the different warm syngas cleanup technologies and advance technology readiness through larger-scale pilot plant testing. However, many of the recommendations from the 2007 Peer Review were incorporated into the Phase 2 work plan, especially those concerning the need to accelerate laboratory programs for multicontaminant work and for suitable regenerable CO_2 sorbents for integrating into the warm syngas cleanup process.

The ability to strategically conduct larger-scale pilot plant testing was also incorporated, but only based on availability of a suitable host site.

Under the new Phase 2 structure, the primary project goal is to develop a warm syngas cleanup technology for chemical applications that meets DOE's programmatic targets, while achieving higher thermal/chemical efficiencies at reduced costs. This goal allowed the combination of laboratory-scale testing, multicontaminant removal, warm regenerable CO_2 sorbents, and integration and intensification of the different warm syngas cleanup technologies to maximize thermal/chemical efficiencies at the lowest possible cost. However, this new goal does not eliminate the opportunity to conduct larger-scale pilot plant field tests, or to expand the list of target trace contaminants to meet changes in DOE's programmatic goals. These changes to Phase 2 effectively implemented many of the recommendations from the 2007 Advanced Power Systems Peer Review relating to the multicontaminant and regenerable CO_2 sorbent R&D.

To help accelerate R&D and accommodate the addition of Se and phosphorus (P) to the list of contaminants, a duplicate system for testing arsine was constructed, commissioned, and operated. Selenium and P contaminants are present in syngas as their hydrides (i.e., hydrogen selenide and phosphine) and are available in gas-phase mixtures like arsine, which means the same testing system can be used for all three of these contaminants. The apparatus can also effectively be used to screen potential sorbent candidates and measure sorbent capacity by adjusting the testing conditions. In addition, the concentration of contaminant is measured by adsorption in a sorbent trap downstream of the test reactor. This allows for rapid switching between the testing of different sorbents, taking maximum advantage of existing low-temperature sorbent materials for these contaminants and extensive expertise at RTI available for the analysis of the contaminants in solid samples. To ensure reliable results relating to the ability of a sorbent to remove a particular contaminant, mass balances are conducted as part of the testing. For Se, the testing program has progressed to permit capacity testing of some of the more promising sorbents identified during screening tests.

In addition to R&D for multicontaminant sorbents, this project has also focused on the development of regenerable sorbents for CO_2. Previous R&D efforts had identified lithium silicate as a very promising sorbent, offering consistent performance over multiple cycles in syngas with or without H_2S at temperatures from 382ºF–1,100ºF. During testing, the sorbent demonstrated activity for the water-gas shift reaction by effectively converting carbon monoxide (CO) into CO_2 and removing it. However, the lithium silicate sorbent's key associated challenge surrounds its ability to be regenerated in a cost-competitive manner while producing a CO_2 stream for storage.

Using the knowledge gained through the R&D associated with the development of the lithium silicate sorbent, RTI proposed an alternative testing scheme to screen potential candidates, based on the following logic. At lower temperatures (392ºF–700ºF), the equilibrium CO_2 partial pressure for the sorbent should be below about 20–30 pounds per square inch (psi). At these conditions, the sorbent can effectively remove >90% of the CO_2 (a fully shifted syngas would have about 300 psi of CO_2 partial pressure). By increasing the temperature of the sorbent to 550ºF–750ºF, the equilibrium pressure for the sorbent increases, resulting in the release of CO_2. The unique feature of this process is that the CO_2 is released at pressure. The higher this release pressure, the less compression (and parasitic power loss) that will be required to prepare the CO_2 byproduct stream for storage.

With this new testing scheme, a promoted sample of magnesium oxide has been shown to have a capacity for CO_2 approaching 60 weight percent (wt%), where its theoretical capacity is 110 wt%, and the ability to produce a CO_2 byproduct at about 150 psi. Although the regeneration at 150 psi is not complete, the dynamic sorbent capacity for a 150 psi CO_2 product would be about 30 wt%. Additional testing has been conducted to optimize promoter composition and concentration. Support material to provide both the chemical stability and mechanical strength to last multiple cycles is also under active testing and investigation.

In addition to these laboratory-based R&D activities, this project will expand the technoeconomic analysis conducted by Nexant, evaluating warm syngas cleanup technologies for power applications to consider such technologies for chemical applications. Because of the large number of chemicals that can be produced from syngas, these specific studies will focus on the chemical production processes with the most demanding specifications, such as Fischer-Tropsch synthesis or methanation. If the warm syngas cleanup technologies can meet these processes' specifications, they will be able to meet the specifications for any of the other chemical production processes.

This project also includes one specific task to effectively use information gained from the Eastman field test, which collected over 3,000 hours of syngas operating experience. RTI is currently supporting researchers at NETL in developing a computational fluid dynamics (CFD) model of HTDP. Once developed, this model will be validated with the field test results from Eastman. After validation, the model will serve as a tool to evaluate and optimize the design of HTDP. Design evaluation and optimization will allow reduction of the effluent sulfur concentration to its minimum value, assisting in meeting the tight sulfur specifications for chemical production and for design of the demonstration plant to be installed at Tampa Electric Company's Polk Power Station near Tampa, Florida (DOE project number DEFE0000489). Preliminary results from this modeling effort have shown promising agreement with the results observed at Eastman.

Relationship to Program:

This project will support important advances in integrated warm syngas multicontaminant cleanup technologies within the gas cleaning area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

Potential benefits associated with successful completion of this project include the following:

- Significant cost reduction for syngas cleaning for chemical applications
- Improvements in the integration and intensification of multicontaminant removal that will help minimize syngas cleanup costs
- Development of a warm CO_2 removal process, based on a regenerable sorbent, that produces a byproduct CO_2 stream at pressures >100 psi
- Validated CFD model supporting demonstration of RTI's warm desulfurization process

Primary Project Goal:

The primary goal is to develop a warm syngas cleanup technology for chemical applications that meets DOE's programmatic targets for warm syngas cleanup performance while achieving higher thermal/chemical efficiencies at reduced costs.

Objectives:

The objectives to be accomplished in Phase 2 of this project include the following:

1. Develop a warm syngas cleaning platform that will produce an effluent syngas product suitable for chemical/fuels production, with specifications matching DOE's warm syngas cleanup performance goals
2. Develop a warm syngas CO_2 capture technology for both power and chemical production with a goal of 90% CO_2 removal and production of a storage-ready CO_2 stream
3. Provide technical support to facilitate successful scale-up of the warm syngas desulfurization process for a demonstration plant

05: FC26-05NT42458

Project Number FC26-05NT42458	**Project Title** Development of an Integrated Multicontaminant Removal Process Applied to Warm Syngas Cleanup for Coal-Based Advanced Gasification Systems			
Contacts DOE/NETL Project Mgr.	**Name** Jenny B. Tennant	**Organization** NETL - Gasification Division	**Email** jenny.tennant@netl.doe.gov	
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Partners	Albert Tsang, Director, ConocoPhillips Scott Lynn, Professor Emeritus, University of California, Berkeley David Seeger, Chief Technical Officer, CrystaTech			
Stage of Development				
__ Fundamental R&D	X Applied R&D	__ Proof of Concept	__ Prototype Testing	__ Demonstration

Technical Background:

Desulfurization systems can be matched to the elevated temperature and pressure conditions of gasification processes (i.e., temperatures in the range of 300°F–700°F and pressures in the range of 400–1,200 pounds per square inch gauge [psig]) and integrated with the warm gas cleanup of other contaminants (trace components and heavy metals). The development of these systems is of critical importance for the early commercialization of advanced gasification technologies that DOE promotes through the Advanced Integrated Gasification Combined Cycle (AIGCC) program.

This project is best considered in two sections, with different cost-share breakdowns and beginning and end dates for the two processes: University of California Sulfur Recovery Process – High Pressure (UCSRP-HP) and the CrystaSulf-Direct Oxidation (DO) process. Both processes directly convert the hydrogen sulfide (H_2S) in coal synthesis gas (syngas) into elemental sulfur (S) at about 285°F. A significant difference between the projects is that the UCSRP is a solvent-based process while the CrystaSulf-DO process uses a dry catalyst.

GTI is also developing a process to remove ammonia (NH_3), chlorine (Cl), selenium (Se), arsenic (As), cadmium (Cd), and mercury (Hg), and will integrate it in the same reactor with the UCSRP-HP. This integration will remove the seven coal-derived syngas contaminants of greatest concern in a single reactor. A system study and economic evaluation will be performed to compare the value of the UCSRP-HP and trace contaminant removal suite to conventional syngas cleanup technologies.

In the UCSRP-HP process, syngas is sent to a reactor column at a temperature above the melting point (247°F) and below the polymerization temperature (310°F) of elemental S, and at a gasification pressure of at least 400 psig. In combination with the GTI trace contaminant removal process, the paired technologies will remove H_2S, NH_3, hydrochloric acid (HCl), and heavy metals, including Hg, As, Se, and Cd, to parts-per-million (ppm) or in some cases to parts-per-billion (ppb) levels in a single process.

In the GTI process, contaminants such as NH_3, HCl, and trace contaminants are removed in the first section of a compound reactor column. This removal is accomplished by a common solvent absorbing H_2S, NH_3, HCl, and trace metals from the feed gas. Ammonia and HCl form a highly soluble ammonium chloride (NH_4Cl) salt; the absorbed heavy metals, As, Cd, and Hg, precipitate out as their very insoluble sulfides. The Se trace metal, present in the syngas as hydrogen selenide (H_2Se), forms a highly soluble ammonium selenide [$(NH_4)_2Se$] under these conditions and remains dissolved in the solvent. A slipstream of the solvent will be treated to remove the soluble and insoluble components.

In the second section of the column, H_2S is converted directly into elemental S by reaction with sulfur dioxide (SO_2) in the liquid phase. Sulfur is only sparingly soluble in the solvent and so forms a separate liquid phase. The liquid S rapidly separates from the solvent phase, allowing the Claus reaction to continue without equilibrium limitations that control gas-phase catalytic systems. The solvent contains a homogeneous liquid catalyst at less than 1% by weight of the solution. The catalyst is a commonly available and inexpensive material that neither degrades nor dissolves in the S. The water formed in the Claus reaction vaporizes and forms part of the syngas. The proposed process is tightly integrated and is expected to be significantly more economical in terms of capital and operating costs because it replaces the sulfur removal processes, acid-gas removal, Claus, Shell Claus Off-gas Treating, and the trace components removal processes used or proposed in conventional schemes by a single unit.

The CrystaSulf-DO is a catalytic system based on the direct oxidation of H_2S to elemental S. Approximately 80%–90% of the feed sulfur will be recovered as liquid S. The remaining H_2S will then be treated with the CrystaSulf process. In the CrystaSulf process, H_2S and SO_2 react in a non-aqueous solvent that has a high affinity for elemental sulfur. The rich solvent is then treated in a crystallizer to recover the sulfur and allow the recycle of the lean solvent. CrystaSulf was selected for the original Southern Company Services/DOE Orlando Clean Coal project, which planned to use low-sulfur Powder River Basin coal, and its integration with direct oxidation will extend its applicability to higher-sulfur coals. The laboratory work on this process has been completed, and a draft topical report is being reviewed.

Relationship to Program:

This project will support important advances in multicontaminant cleanup technologies through the gas cleaning focus area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

If this project is successful, the industry will have a lower-cost option for producing “clean” syngas. The UCSRP-HP and CrystaSulf-DO processes are expected to demonstrate the removal of multiple contaminants, including H_2S, carbonyl sulfide, Hg, Se, As, NH_3, and HCl, from the warm syngas at a lower cost than other current and developing technologies. The team will resolve research issues at the laboratory and bench scale prior to larger, more expensive pilot-scale testing.

Primary Project Goal:

The primary goal of this project is to develop an integrated multicontaminant removal process in which H_2S, NH_3, HCl, and heavy metals (including Hg, As, Se, and Cd) present in coal-derived syngas can be removed to specified levels in a single/integrated process step. The project aims to achieve this task at significantly lower cost than that of conventional technologies.

Objectives:

The project objectives are to reduce syngas contaminants to the following maximum post-cleanup levels:

1. Reduce NH_3 to 0.1 percent by volume (vol%)
2. Reduce HCl to 1 ppm
3. Reduce Hg to 5 parts per billion by weight (ppbw)
4. Reduce Se to 0.2 ppm
5. Reduce As to 5 ppb

06: DE-FC26-05NT42469

Project Number	**Project Title**			
DE-FC26-05NT42469	Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants			
Contacts	**Name**	**Organization**	**Email**	
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Principal Investigator	Douglas S. Jack	Eltron Research & Development, Inc.	djack@eltronresearch.com	
Partners				
Stage of Development				
__ Fundamental R&D	__ Applied R&D	__ Proof of Concept	X Prototype Testing	__ Demonstration

Technical Background:

This technology uses a dense metallic-composite membrane system to separate hydrogen (H_2) and carbon dioxide (CO_2) from a coal-based synthesis gas (syngas) stream. This system also has wider applicability to other hydrogen-containing streams.

In earlier programs, Eltron Research and Development, Inc. evaluated ceramic materials, ceramic-metallic composites (cermets), and metallic alloy membranes. Based on that work, the metallic alloy-based systems were chosen for further investigation because these composite membranes have been shown to meet the DOE 2010 targets for flux, selectivity, and cost.

The metallic composite membrane has been operated at 1,000 pounds per square inch gauge (psig) and at differential pressure of up to 500 psig on simulated syngas compositions. The membrane life has been shown to be about 8,000 hours. Some early work on impurity testing has shown membrane tolerance to sulfur at levels up to 20 parts per million (ppm). The membrane has also been integrated into a water-gas shift (WGS) reactor, facilitating high conversion of carbon monoxide (CO). Process design and economic studies have shown cost and thermal efficiency benefits. The membranes have been tested with all syngas components including CO, CO_2, hydrogen sulfide (H_2S), water (H_2O), and H_2. The membranes have also been exposed to live syngas from a coal gasifier and tested following exposure. These exposure tests were not flux tests. A unit is currently being designed for installation in the first quarter of 2010 for testing on an actual coal gasifier slipstream.

Relationship to Program:

This project will support important advances in hydrogen production and CO_2 capture through the gas separation pathway of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

When the technology is commercialized, it will contribute several benefits to the operation of a FutureGen-style plant:

- High-purity hydrogen (>99.999%) will be able to be delivered from coal-based synthesis gas at lower cost than from conventional technology.

- Retention of CO_2 at high pressure will lower the capture cost and improve the higher-heating-value efficiency of a plant capturing CO_2 for storage, primarily by significantly reducing compression requirements.
- The technology may enable process simplification and intensification when incorporated into membrane reactors (this concept is demonstrated under a separate Small Business Innovation Research contract).
- The technology can be applied for recovery of H_2 from other systems, such as natural gas partial oxidation, diesel or naphtha reforming, refinery streams, chemical processes, and fuel processing for fuel cells.

Primary Project Goal:
The primary goal of this project is to develop a high throughput, low-cost H_2 separation system suitable for application with coal-based syngas. This system will have improved tolerance for contaminants (e.g., sulfur and mercury) and will enable cost-effective capture of CO_2 for storage.

Objectives:
The project objectives are grouped into the following five major areas:

1. Materials Development:
   - 1.1 Develop and test membrane alloy systems that give the best flux without risk of membrane embrittlement
   - 1.2 Develop catalyst compositions that do not limit flux and that provide the requisite tolerance to impurities
   - 1.3 Understand the importance of the interface between the membrane and catalyst
2. Performance Screening:
   - 2.1 Establish the range of operating conditions for the system with the best performance using WGS composition syngas
   - 2.2 Evaluate the effect of impurities on performance
   - 2.3 Perform life tests of membranes for longer than 600 hours
3. Process Design:
   - 3.1 Integrate the system into integrated gasification combined cycle flow sheets, testing different configurations (i.e., with and without coproduction of power and H_2)
   - 3.2 Evaluate the impact of different impurity management techniques
   - 3.3 Compare economics, including capital expenditures and operating expenses, to the economics of alternative technologies
4. Mechanical Design:
   - 4.1 Address manufacturing issues for system scale-up, taking into account maintenance costs, initial capital costs, and system robustness;
   - 4.2 Address issues such as welding, sealing, catalyst deposition techniques, and alloy manufacture for tubular system.
5. System Scale-up (Currently at 1.5 lbs/day H_2 production, whereas the commercial module is expected to be at ~25–40 tons per day [TPD] scale):
   - 4.1 Design, build, and operate a 12 lb/day system on a coal-based syngas slipstream, developing operating procedures and gathering initial engineering data for further scale-up
   - 4.2 Complete the design for a nominal 120–220 lb/day unit for testing on coal-based syngas
   - 4.3 Build and operate a 120–220 lb/day unit followed by the design, fabrication, and operation of 4 TPD unit to complete the engineering package for commercial design and demonstrate large-scale manufacturing capabilities (beyond 2010 [not yet budgeted])

07: DE-FC26-04NT42237

Project Number DE-FC26-04NT42237	**Project Title** Development of Technologies and Capabilities for Coal Energy Resources			
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Partners	ExxonMobil Research and Engineering Company Alberta Energy Research Institute University of North Dakota Energy and Environmental Research Center			
Stage of Development				
__ Fundamental R&D	__ Applied R&D	__ Proof of Concept	_X_ Prototype Testing	__ Demonstration

Technical Background:

The dry solids pump program is based on the physical concept of particle-to-particle lock-up that allows bulk solids, when contained in a certain configuration, to generate very high mechanical forces. Further, the ability of particulate solids to provide a seal against gas pressure when in a highly consolidated condition enables the potential for injection against gas pressure. This concept has been proven in other, previously funded DOE research efforts using a rotary concept. The Pratt and Whitney Rocketdyne, Inc. (PWR) dry solids pump utilizes a linear concept that offers the potential for much higher efficiencies and flexibility in configuration over a rotary layout. Component testing, included in this program, has confirmed the effectiveness of the linear concept to both generate the mechanical forces needed to overcome the target pressure and also seal against gas at that pressure. The linear pump concept offers the potential for simple scalability with a basic machine configuration. Further, the design provides the flexibility to change internal configurations and materials easily to test different configurations.

The following sections outline selected recent project accomplishments:

Subscale Dry Solids Pump Component Testing (Subtask 2.10)

Hardware for four component test rigs was manufactured and delivered to the test facility. The moving wall testing (MWT) rig, outlet force evaluation testing (OFET) series, and outlet pressure testing (OPT) series were completed. In addition, testing for the first rig of the outlet flow testing (OFT) was also completed. These test rigs will provide data to be used in the detailed design of the dry solids pump. The MWT rig allows testing to determine the level of coal consolidation that the linear track concept can accomplish. The OFET measures friction in stationary walls. These two test methods measure similar forces with two different frames of reference: in the MWT, the walls move, imparting force on the coal; in the OFET, the coal is pushed as a solid mass and friction is measured on the stationary walls. The OPT tests will validate the pressure performance of a rectangular outlet configuration with regard to gas leakage rates for various fuel types. The OFT tests are designed to evaluate different options for deconsolidating fuel from a compressed plug back into a finely powdered consistency with void fractions and particle sizes compatible with dense phase feeding and high-efficiency gasification.

5.1.2.1. MWT Rig Testing

The MWT rig allows testing to determine the level of coal consolidation that the linear track concept can accomplish. This modular design is flexible so that the configuration can be changed, thus allowing for optimization of the component design. The size of the track required to achieve sufficient material loads of the contained coal is measured, and results are used to size the prototype pump.

This year, moving wall testing continued under a variety of different test parameters. In an effort to produce the highest material loads possible, new walls were fabricated to contain the coal and prevent deflection of the test rig. This rig modification led to consistently producible solids pressures above 1,000 pounds per square inch (psi), a good indicator for pump operability. Subsequent tests were conducted in a converging wall configuration that did not allow the rig modification to support the high material loads by using the wall clamping modification due to the converging geometry. A database of prior tests without the modified wall clamping modification permitted a comparative analysis of this converging wall concept.

The MWT tests during the quarter were successful in demonstrating several key characteristics of the linear traction drive concept. Given an appropriately chosen aspect ratio of coal column height to wall spacing, the moving wall concept was proven to generate material consolidation loads in excess of 2,000 psi. Such ratios of height to width were utilized for the dry solids pump design. Data based on the wall design did not provide a benefit to the machine design, and no further effort will be undertaken. Some tests indicate that if the pump is allowed to run in a “transition” condition, the pressures may increase with time at a slightly slower delivery rate, which suggests that there is the possibility to operate a given pump configuration at higher gas pressures but at reduced fuel mass flow rate.

5.1.2.2. Outlet Configuration Testing (OCT)

The outlet configuration testing (OCT) program comprises three test rig configurations, or phases, that evaluate the friction losses, permeability, and geometry of the pump outlet. Each phase of OCT testing provides data supporting the pump design to ensure an acceptable gas seal and particle size distribution at the pump exit.

5.1.2.2.1. Outlet Force Evaluation Testing (OFET)

The OFET test series represents the first phase in the OCT test program. This phase serves to gather frictional loss data for the parallel, gas sealing portion of the outlet in an atmospheric environment. While the outlet will see a pressure gradient in the pump, the ability to test under atmospheric conditions allows for the mapping of test processes and anchoring to MWT results in an easily workable environment. The OFET results also provide baseline data for the outlet pressure testing, where the behavior of the granular material may vary under a pressurized environment. During the quarter, 16 OFET tests were conducted, and they all produced friction values that are in agreement with basic coal compaction and friction tests conducted with traditional shear cells at Jenike and Johansing. The tests also provided valuable information for producing a baseline performance prior to gas leakage/friction combination tests, and for developing procedures for the gas permeability/friction combination tests.

5.1.2.2.2. Outlet Pressure Testing (OPT)

The OPT testing will determine the pressure performance of outlet configurations with regard to gas leakage rates for various fuel types. The OPT test rig will be configured for operation up to 1,000 psi outlet gas pressure.

Detailed Design (Subtask 2.11)

A formal design review will be conducted in December 2009. This review will look at the design and development activities to determine if requirements are being met and determine if the design has the maturity to progress into the fabrication stage.

This year, the design of the mechanical elements of the pump assembly continued. Roller bearing performance and geometry requirements were finalized in collaboration with a commercial bearing supplier. The moving wall belt link and pin assembly solid model geometry was developed and submitted for stress and deflection analysis. Pressure containment and pressure relief system requirements for the pump case are being evaluated based on various start-up, shutdown and cutoff scenarios. The American Society of Mechanical Engineers boiler and pressure vessel coded outlet duct design is progressing using the predicted pressure and static loads. A design review of the current pump concept was completed in June. The design was presented to PWR discipline management and University of North Dakota Energy and Environmental Research Center (EERC) personnel for review and comment. No significant issues were generated during the review. Active hopper drawings were developed and released to the approval cycle. The active hopper will form part of the expanded test program to characterize materials flow and flow interruption minimization for the expanded-capacity pump. Pump system-to-facility interface requirements have been discussed with EERC. The design effort has been expended to develop integration with the existing EERC facility and determine modifications required for installation. Concepts for tooling to support pump assembly, fabrication, and handling were identified and preliminary tooling designs were started. The manufacturing planning schedule was started in an effort to determine the work flow and required delivery events. Work included completion of the pressure testing and integration of the results into the design. The design effort will focus on detailing internal and case components as well as an effort to identify commercial components. The pump cost and schedule will also be updated based on vendor inputs.

Coal/Biomass Mixture Analysis (Subtask 5.1)

The feasibility of biomass/coal mixture blends as an alternate feedstock to the PWR Compact Gasification System is also being performed. This evaluation will be conducted in four subtasks:

1. Fossil fuel-biomass mixture laboratory-scale test plan
2. Fossil fuel-biomass mixture laboratory-scale tests
3. Fossil fuel-biomass mixture analysis
4. Coal-biomass mixed-feed economic analysis

Laboratory testing was completed and economic trade studies will now be conducted on three to four coal/biomass blends. In addition, dry extrusion pump modeling will also be initiated with these three to four coal/biomass blends to determine expected changes in pump performance and pump size when switching from 100 weight percent coal feedstocks (having much lower unconsolidated void fractions) to these more porous coal/biomass blends.

During the quarter, EERC completed following ASTM analyses (or equivalent) on the wood, corn stover, and switchgrass biomass materials and the North Dakota lignite: ASTM D3176-89, D5142-04, D5865-07, D2638-06, D6683-01, and D197-87. Similar data on the Illinois #6 bituminous and Powder River Basin subbituminous coals were provided in previous DOE reports. Although all three biomass materials were milled to particle size distributions (PSDs) and moisture contents in the expected ranges that are consistent with the coals they will be subsequently blended with, it is worth noting the significantly lower bulk densities and heating values of biomass when compared to coal. These differences will be evaluated in future economic and pump performance analyses. The specific power consumption for milling the biomass materials to the PSDs and moisture levels attained were as follows: (a) 0.50 kWh/kg for +200 mesh wood; (b) 0.43 kWh/kg for -200 mesh wood; (c) 0.33 kWh/kg for +200 mesh corn stover and switchgrass, and (d) 0.28 kWh/kg for -200 mesh corn stover and switchgrass. This represents about one-third of the heating value of the biomass when converted to a mechanical-electrical power equivalent. The program's future economic assessment will explore methods of lowering the milling power consumption by optimizing mill performance. For example, more power was consumed by the mill while producing the coarser (+200 mesh) material than while producing the finer (-200 mesh) material. ASTM testing with the pure coal and biomass samples was completed. ASTM testing with the 50/50 and 90/10 coal/biomass blends is currently in process. Once these ASTM tests are complete, economic and extrusion pump modeling efforts will begin to determine the best blends for further work. This further work will involve extrusion pump semi-rig testing and a detailed preliminary front-end engineering design (FEED) type of study.

Relationship to Program:

This project will support important advances in dry solids pumps within the advanced gasification area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle program.

A successful dry solids pump will profoundly impact coal and other solid-fuel gasification processes. This machine will provide a reliable and affordable method for delivery of gasifier feedstocks at high pressure. Further, the concept offers a level of reliability and feed accuracy far exceeding lock-hoppers, the only other feeding option. The dry solids pump will significantly lower the capital cost of plants and the overall cost of electricity through lower operating costs, in part by dramatically reducing gas consumption for the plant. The dry solids pump, by its design, also has the potential for offering significant flexibility to gasifier operators by feeding low-cost fuels including lignite and biomass blends, thus lowering overall operating and energy costs. This can include reduction in the preparation costs of such fuels by allowing higher moisture contents and minimized preparation when installed on fuel-flexible and transport gasifiers.

Primary Project Goal:

The project goal is to develop and test a prototype commercial-scale dry solids pump that meets gasification industry requirements and is able to feed a gasifier operating at 1,000 psi.

Objectives:

The project objective is to complete the following active and remaining tasks associated with the dry solids pump:

2.10 Subscale dry solids pump component testing
2.11 Detailed design of dry solids pump
2.12 Dry solids pump construction
2.13 Dry solids pump test plan
2.14 Dry solids pump tests
2.15 Low-rank coal characterization
2.16 PWR pump cost-benefit analysis

4.1 Test plan for subscale dry solids pump component testing for transport gasifier feed
4.2 Transport gasifier subscale tests
4.3 Fossil fuel-biomass mixture analysis

5.1 Test plan for subscale dry solids pump component testing for fossil fuel-biomass mixture
5.2 Fossil fuel-biomass mixture subscale tests
5.3 Fossil fuel-biomass mixture analysis
5.4 Coal-biomass mixed-feed economic analysis

6.1 Determine extent of pump test facility modification needed for pilot-scale tests of coal-biomass mixtures
6.2 Coal-biomass solids pump modification or fabrication
6.3 Coal-biomass mixture 600 tons per day (tpd) test plan
6.4 Fossil fuel-biomass mixture 600 tpd tests

7. Management

08: DE-FC26-06NT42758

Project Number DE-FC26-06NT42758	**Project Title** Co-Production of Electricity and Hydrogen Using a Novel Iron-Based Catalyst			
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Partners	Archer Daniels Midland Sud-Chemie, Inc.			
Stage of Development				
__ Fundamental R&D	__ Applied R&D	X Proof of Concept	__ Prototype Testing	__ Demonstration

Technical Background:

Introduction

Hydrogen (H_2) is a vital feedstock crucial for manufacturing and chemical production. Several examples of large commercial H_2 utilization include desulfurization and upgrading of crude oil and production of ammonia for fertilizers. Expanding H_2 production in the United States using commercial technologies in support of a hydrogen infrastructure faces strong opposition from efforts to reduce carbon dioxide (CO_2) emissions and dependence on foreign energy feed stocks such as oil and liquefied natural gas (LNG). One option that addresses all of these concerns is hydrogen production from domestic coal coupled with carbon capture and storage (CCS) technologies. The DOE Hydrogen from Coal Program, administered by the Office of Fossil Energy and managed by NETL, conducts and funds research to develop H_2 from coal technologies. With the support of DOE-NETL, RTI International (RTI) is developing the steam-iron process (SIP), a chemical looping technology, for the co-production of H_2 and electricity in integrated gasification combined cycle (IGCC) facilities.

RTI's SIP Technology

The SIP is a two step chemical looping process based upon iron reduction/oxidation chemistry. In the first step, iron oxide (Fe_3O_4) is reduced to a lower oxidation state by a reducing gas:

$$Fe_3O_4 + 4H_2 = 3Fe + 4H_2O \qquad \text{[Reaction 1]}$$
$$Fe_3O_4 + 4CO = 3Fe + 4CO_2 \qquad \text{[Reaction 2]}$$

In the second step, the reduced iron is oxidized with steam, producing a pure H_2 product:

$$3Fe + 4H_2O = Fe_3O_4 + 4H_2 \qquad \text{[Reaction 3]}$$

The SIP was commercially practiced in the early 20th century and represents one of the oldest industrial methods of producing H_2. Previous commercial SIP technologies used iron ore at high temperature (800°C–1,100°C), which focuses on using H_2 as the reducing agent. Although iron ore represented a low cost agent, problems with reactivity, stability, sintering, and attrition resulted in very high consumption rates for the iron ore. The unfavorable economics associated with this high iron ore consumption eventually allowed steam methane reforming to become the commercial standard for production of industrial H_2.

Because many of the problems (chemical activity, stability, and sintering) were a direct consequence of operating at temperatures greater than 800ºC, RTI's strategy to overcome the issues plaguing SIP technologies has been to operate at 450°C –550°C by utilizing CO as the reduction agent. At lower temperatures, sintering of the iron-based materials should be significantly reduced, improving activity and stability. RTI's SIP technology will also simplify thermal integration into an IGCC facility.

RTI has leveraged advances in catalyst preparation techniques to produce particles with supported nanostructured iron oxide crystallites, essentially engineered to provide the necessary chemical (activity and stability) and physical (attrition) properties. RTI's SIP technology also makes use of the development of the commercial reactor technology used in fluid catalytic cracking in petroleum refining to circulate the engineered iron oxides between a reducing reactor and an oxidizing reactor. Fluid bed reactor systems allow high reactant throughput, excellent temperature control, and a relatively small system footprint. However, these fluid bed reactor systems require physically stronger catalysts to withstand the stress and abrasion associated with circulating the catalyst and higher chemical activity to achieve the high throughput.

Application of SIP Technology

RTI's SIP is composed of a dual fluidized-bed reactor that includes reducer and oxidizer reactors, and a steam condensation system. One potential source of the reducing gas necessary to drive the SIP is the syngas generated during gasification of coal. Figure 8-2 presents the SIP process flow diagram, integrated into an IGCC plant. One benefit of this integration scheme is that the effluent gas from RTI's SIP, which still has a significant amount of H_2, can be used for co-generation of electrical power. The competing commercial process technology is pressure swing adsorption (PSA) combined with water-gas shift.

Syngas is introduced into RTI's SIP at the base of the reducer reactor (T = 500°C). Because of the high operating temperature, RTI's SIP efficiently integrates with warm syngas desulfurization. In the reducer, iron oxide is mixed with the syngas and converts CO to CO_2 according to Reaction 2. The syngas/iron oxide mixture exits the reducer and the particles are separated by a cyclone. The syngas passing through the cyclone can be further processed to capture the remaining CO_2 before combustion in a combustion turbine for power production. The reduced iron particles, leaving the cyclone, fall into the oxidizer (T = 500°C), where they react with steam to produce H_2 according to Reaction 3. The iron oxide particles exit the bottom of the oxidizer and are pneumatically conveyed to the reducer completing the iron redox cycle. The H_2/steam product is cooled in a series of heat exchangers which condense the steam and yield a pure, high-pressure H_2 product.

The SIP offers extensive flexibility with operation across a wide pressure range suitable for commercial coal gasification systems (600 psig) and biomass gasification systems (atmospheric), allowing effective integration with most gasification technologies. This process can also produce high purity H_2 with air-blown gasification technology, which is not possible with PSA or membrane technologies and would permit biomass-based renewable H_2 production.

Optimally, the RTI SIP technology would be coupled with dry oxygen-blown coal gasification and warm-gas cleanup technologies, yielding a high capacity thermally integrated H_2 production technology package.

Advantages and Challenges

When compared to competing chemical looping H_2 production processes, RTI's SIP technology exhibits the following advantages:

- Lower operating temperature (550°C)
- Efficient thermal integration with IGCC technology
- Feedstock flexibility
- High purity H_2 production with all gasification technologies

The specific challenges of producing H_2 using an iron-based chemical looping process are:

- Increasing material reactivity, stability, and strength
- Reducing deactivation by H_2S or coking
- Controlling solids circulation requirements

Relationship to Program:

This program will support important technology advances in the steam-iron processes focus area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program. Success in Phase II of this project will offer the following benefits:

- RTI SIP will have demonstrated the ability to produce a high-pressure, high-purity H_2 product.
- Key process information for scale-up of RTI's SIP dual circulating fluidized-bed reactor system will be acquired.
- Key operating data necessary for a more rigorous economic evaluation of the SIP will have been collected, including improved estimates for material makeup due to attrition and chemical deactivation.
- RTI SIP will be ready for pilot plant-scale demonstration at a commercial gasifier site.

Primary Project Goal:

Develop a commercially and economically viable SIP system using engineered iron material comprised of supported nanostructured iron oxide crystallites, to produce high purity high pressure H_2 from syngas.

Objectives:

This project consists of three phases.

Phase I objectives include the following:

1. Develop an attrition-resistant, iron-based material
2. Demonstrate feasibility of stable multi-cycle redox of iron material using syngas at temperatures greater than 800ºC
3. Complete preliminary technoeconomic of the SIP to demonstrate cost competitiveness

Phase I was successfully completed. Several novel iron-based material formulations were identified that demonstrated high activity with syngas compositions representative of different commercial gasifiers at temperature greater than 550ºC. The technoeconomic analysis demonstrated that RTI's SIP resulted in a lower cost for H_2 production than a commercial PSA process.

Building on these achievements, Phase II objectives include the following:

1. Produce 100 lb batches of the most promising catalyst formulations using commercial manufacturing equipment and processes
2. Design and fabricate an SIP prototype reactor system
3. Demonstrate operational feasibility of the SIP prototype reactor system
4. Update technoeconomic analyses
5. Develop engineering design package for pilot-plant demonstration

Based on the work completed, Phase II should also be successfully completed. This will set the stage for Phase III, the objective of which is to complete a pilot plant field demonstration of RTI's SIP during integration with a commercial gasifier.

RTI has already begun planning for this field test in Phase III, and is working with ADM to identify potential host sites for a pilot plant demonstration. RTI is also looking at using the engineering package for a pilot plant demonstration to be completed as part of Phase II as a foundation for this field test demonstration in Phase III. Preliminary design specifications for a larger pilot plant producing approximately 1,000 lbs H_2/day are being prepared.

09: DE-FC26-99FT40685

<table>
<tr><td>Project Number
DE-FC26-04NT42237</td><td colspan="4">Project Title
Single-Crystal Sapphire Optical Fiber Sensor Instrumentation</td></tr>
<tr><td>Contacts
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<tr><td>Partners</td><td colspan="4">Global Energy Co., Wabash Gasifier Facility, Wabash, IN (Phase I)
Tampa Electric Co. (TECO), Tampa, FL (Phase II)
Eastman Chemical Co., Kingsport, TN (Phase III)
National Energy Technology Laboratory (NETL) Turbine Lab, Morgantown, WV (Phase III)</td></tr>
<tr><td colspan="5">Stage of Development</td></tr>
<tr><td>__ Fundamental R&D</td><td>_X_ Applied R&D</td><td>__ Proof of Concept</td><td>__ Prototype Testing</td><td>__ Demonstration</td></tr>
</table>

Technical Background:

The need for reliable temperature measurement inside coal gasifiers has been recognized for over a decade (a DOE solicitation for temperature measurement was issued in 1999) and continues to be a priority measurement need. Accurate temperature measurement is essential for safe and efficient operation and would help increase the reliability of gasification-based processes. Prior techniques for inferring temperature in a gasifier are primarily limited to precious metal thermocouples and other techniques involving downstream measures and calculations to infer temperature. These approaches are acknowledged by industry to have drawbacks including rapid failure and inaccuracy. Rapid failure is a result of the harsh environment, which includes extreme physical conditions such as high temperature, high pressure, corrosive agents, strong electromagnetic interference, and high-energy radiation exposure. This situation has opened new but challenging opportunities for novel sensing approaches to provide robust, high-performance, and cost-effective techniques capable of operating in those harsh environments.

The temperature sensors developed in this project were designed to realize the myriad advantages of optical sensors, such as immunity to electromagnetic interference, resistance to chemical corrosion, avoidance of ground loops, high sensitivity, wide bandwidth, and capability for remote operation. Through the use of a single-crystal sapphire material, which is chemically inert and has a high melting point, the developed sensors have the potential for widespread deployment in harsh-environment applications where high temperatures and chemically corrosive environments exist. This project has focused on the development of a sensor capable of operating in a slagging coal gasifier and other harsh environments.

Prior work under this project was completed in two phases, each with a separate focus. Phase I of the program, from October 1999 to April 2002, was devoted to developing a sensing schema for use in high-temperature, harsh environments.

Different sensing designs were proposed and tested in the laboratory. Phase II of the program, from April 2002 to April 2009, focused on bringing the sensor technologies, which had already been successfully demonstrated in the laboratory, to a level where the sensors could be deployed in harsh industrial environments and eventually become commercially viable through a series of field tests. Also, a new sensing scheme was developed and tested with numerous advantages over all previous schemes in Phase II.

In Phase I, three different sensing principles were studied: sapphire air-gap extrinsic Fabry-Perot sensors; intensity-based polarimetric sensors; and broadband polarimetric sensors. Black body radiation tests and corrosion tests were also performed in this phase. The outcome of the first phase of this program was the selection of broadband polarimetric differential interferometry (BPDI) for further prototype instrumentation development. This approach is based on the measurement of the optical path difference between two orthogonally polarized light beams in a single-crystal sapphire disk. At the beginning of Phase II, in June 2004, the BPDI sensor was tested at the Wabash River coal gasifier facility in Terre Haute, Indiana. Due to business conditions at the industrial partner and several logistical problems, this field test was not successful. An alternative high-temperature sensing system using sapphire wafer-based extrinsic Fabry-Perot interferometry was then developed as a significant improvement over the BPDI solution. The wafer-based sensor developed in Phase II resulted in a more compact, robust packaged probe design, which ultimately proved more feasible for reliable temperature sensing in coal gasifier applications.

From June 2006 to June 2008, three consecutive field tests were performed with the new sapphire wafer sensors at the Tampa Electric Company (TECO) coal gasifier in Tampa, Florida. One of the sensors survived in the industrial coal gasifier for 7 months, over which time the existing thermocouples were replaced twice. In subsequent field tests, the sensors failed due to signal degradation over a period of several days to two weeks, under varied thermal cycling conditions. Analysis of the failed field tests suggests that mechanical failure of the packaging, and the resulting deposition of solid coal slag on the sensing fiber, played a major role in the sensor failure. At the same time, the outcome of the successful TECO field test suggests that the sapphire wafer sensor has very good potential to be commercialized. Given these competing observations, it was determined that additional development is needed to resolve packaging and sensor protection issues, after which the sapphire temperature sensor will be a viable commercial technology.

Based on the results of the previous work, Phase III of the project began in September 2009 with the goal of improving the sensor packaging and probe technologies and demonstrating them in the coal gasifier at Eastman Chemical Company in Kingsport, Tennessee. An additional application, use of the sensor in a turbine engine, will be developed and demonstrated in a laboratory test environment at NETL’s turbine laboratory. Through use of additional materials and probe and sensor element design and testing, the focus of the Phase III effort will be improvement of the sensor’s reliability and longevity in the gasifier environment.

Materials Selection

During the initial sensor development, single-crystal sapphire and fully stabilized zirconia were chosen as candidate materials for evaluation due to their optical properties, high mechanical strength, temperature stability, wear resistance, and chemical inertness. Possessing a high melting temperature (over 2,000ºC) and good mechanical properties, chemically inert single-crystal sapphire and fully stabilized zirconia are attractive candidates to be employed under adverse conditions (such as in the presence of organic solvents and acids), at elevated temperatures, and in chemically corrosive environments. Sapphire was identified as a particularly attractive candidate because of its availability in the form of single-crystal sapphire optical fibers.

EFPI Sapphire Temperature Sensor

A sapphire-fiber-based extrinsic Fabry-Perot interferometer (EFPI) sensor was first investigated as the basis for the high-temperature sensor. Similar to other successful EFPI sensors, the design involved two sapphire fibers and a sapphire or zirconia tube. Temperature measurement was to be performed by monitoring the air gap between two sapphire fibers, through optical interference.

Because of the large numerical aperture (about 1.64) of the sapphire fiber, a very weak interference signal is generated in the cavity formed by two sapphire fibers. Also, the intermode dispersion in the multimode sapphire fiber degrades the interference fringes generated outside the fiber; thus, it is hard and time-consuming to fabricate sapphire EFPI sensing elements and almost impossible to deploy them in industrial environments, where external vibration can excite many higher-order modes in the sapphire fiber, totally destroying the interference fringes from the fiber gap.

BPDI Sapphire Temperature Sensor

To alleviate these concerns, an alternate sensor based on the temperature-depended birefringence of a single-crystal sapphire disk was developed during Phase I. Due to the crystallographic arrangement of the atoms in single-crystal sapphire, the material exhibits an inherent birefringence, a dependence of the refractive index on the direction of incident polarization. For a wavelength of 589 nm, $n_o = 1.768$, and $n_e = 1.760$, yielding a birefringence of 0.008. One single-crystal sapphire disk with inherent birefringence is sandwiched between a polarizer and an analyzer, whose polarization directions are parallel to each other along the z-axis direction. The principal axes (i.e., the f-axis and s-axis) of the sapphire disk are oriented at 45º with respect to the z-axis direction. At the exit of the disk, the phases of the two orthogonal states are shifted by a quantity Φ, and the emergent state of polarization is usually elliptical. In order to uncover the phase shift Φ introduced by the disk, the emerging light is analyzed by a polarization analyzer. The phase shift is determined by the magnitude of the birefringence and the relative length difference traveled by the differently polarized light. Because both the birefringence and thickness of the sapphire material are a function of temperature, the magnitude of the differential phase shift is also temperature dependent. Therefore, by sensing the magnitude of this phase shift, the temperature can be uniquely determined.

A reflection-mode BPDI sensing structure was designed to enable packaging conducive to application in the coal gasifier. A single-fiber collimator was used to collimate input light and to collect light reflected by a 45-45-90 degree zirconia prism after the sapphire sensing disk. The prototype sensor, consisting of a sapphire protection tube and extension tube (a round, single-bore cast alumina 99.8% tube), was fabricated with a total length of about 2 m, and diameter of 3.5 cm. The sensing element (a sapphire disk) was located in the protection tube, the end of which was placed into a high-temperature furnace for laboratory testing. At the relatively low-temperature end, both the optical polarizer and optical fiber collimator were inserted into the tube.

Black Body Radiation Reduction and Laboratory Testing of the BPDI Sensor
A simple scheme involving input light modulation and digital finite impulse response (FIR) filtering of the collected output spectrum was developed to handle noise from black body radiation at high temperatures. Using this algorithm, the BPDI sensor was able to achieve better than 4°C accuracy, as compared to a B-type thermocouple, over the range of 1,000°C to 1,600°C in laboratory testing.

Field Test of the BPDI Sensor
A fully-packaged sensor probe was designed and constructed for field testing in the coal gasifier at Wabash River Energy in Wabash, Indiana. The packaging consisted of a stainless steel flange and pipe, coupled to an alumina/sapphire tubing assembly for the high-temperature probe. A self-contained optoelectronic signal demodulation package was constructed and connected to a computer for remote data monitoring at Virginia Polytechnic Institute and State University (Virginia Tech). Installation of the probe, performed in 2004 by technicians at the Wabash facility, resulted in mechanical damage to the sensor probe, rendering it unusable.

Wafer-Based Sapphire Sensor
During Phase II of the project, an initiative was undertaken to reduce the size of the sensor probe and improve its mechanical stability. A wafer-based EFPI approach was developed to allow the use of sapphire optical fiber and eliminate the need for free-space optics, such as collimators and prisms used in the BPDI system. Unlike the fiber-based EFPI, demonstrated to have limited feasibility in Phase I, the sapphire wafer provides inherently flat, parallel interference surfaces, eliminating the modal issues that plagued the earlier design.

A simple interrogation system was developed consisting of an 850 nm light emitting diode (LED) source, a multimode (MM) 3-decibel (dB) coupler, and an Ocean Optics S2000 spectrometer. A 99.8% alumina tube was used as the supporting structure, to which both a 59 μm thick sapphire wafer and a 75 μm (diameter) sapphire fiber were bonded using high-temperature alumina adhesive. A novel technique, involving alternating heating and mechanical movements, was developed to couple the sapphire fiber to a 100/140 μm MM silica fiber for convenient connection to the source/detection systems.

Signal Demodulation and Laboratory Testing of the Wafer-Based Sensor
Light from the LED travels through the 3-dB coupler to the sensor head and is reflected. The reflected signal propagates back to the spectrometer, from which the spectrum data is retrieved and processed by a computer.

Several novel signal demodulation methods have been developed over the course of the project, all of which are based on calculating the temperature-dependent thickness of the sapphire wafer from the frequency of the broadband interference fringes. The most accurate method involves digital filtering, Hilbert transform normalization, phase unwrapping, and linear regression.

Laboratory testing of the sapphire wafer sensor was performed in comparison to a B-type thermocouple over the range from 230°C to 1,600°C. Over this range, the sensor demonstrated a +/-3°C accuracy, corresponding to +/-0.2% of full scale.

Field Test of the Sapphire Wafer Sensor

Field testing of the sapphire wafer sensor was performed in three separate experiments at the TECO coal gasifier facility. A high-temperature sensor probe was designed and constructed to mate, through a fiber optic feed-through, to the gasifier outer wall. Made with a series of alumina and single-crystal sapphire tubes, the outer package was designed to protect the sensor from mechanical damage and corrosion inside the gasifier. The far end of the probe was designed to reach just to the edge of the refractory wall, the thickness of which was reduced over time by corrosion, which left the probe extended into the hot region of the gasifier.

During the first and most successful field test, one of the three individual sensor elements installed in the probe package provided accurate temperature data for seven months. The sensor survived through multiple thermocouple replacement procedures, demonstrating its tremendous potential as a long-term temperature monitoring device for coal gasifier applications.

In the second and third TECO field tests, several modifications were made to the sensor packaging in an attempt to address the issue of refractory shift. Because the gasifier lining is made of multiple concentric layers of refractory bricks, each of which expands at a different rate during heat-up, shear forces experienced by the probe are a major concern. In all three field tests, postmortem analysis suggested that cracking of the outer packaging, and the subsequent deposition of coal slag on the optical fiber and sensor head elements inside the packaging, is the dominant cause of failure for the sensor. In the case of the second and third field tests, the sensor lost its signal after periods of 30 and 9 days, respectively.

Work in Phase III: Sensor and Package Improvement

The results of Phases I and II clearly show that the developed sapphire fiber/wafer-based temperature sensor has the potential to perform long-term measurements in a coal gasifier, where no other technology can survive. These results also show that work needs to be done, particularly with regard to packaging of the sensor, to minimize risks due to corrosion and mechanical failure. Such a package must be able to withstand shifting of the refractory gasifier lining, preventing the deposition of coal slag on the fiber and sensor elements during long-term operation.

The Phase III effort will focus on modifying the sensor and package design to better protect the sensor element. A blank package probe, consisting of only the outer package materials, will be constructed and tested in the coal gasifier, and postmortem analysis will be used to generate an improved package design. Sensor head and lead-in fiber design modifications will also be considered as part of a cohesive sensor protection solution designed to maximize longevity in the harsh environment. A series of full-scale field tests will be used to demonstrate the developed technology and bring it closer to commercial use. Additional applications in turbine engine temperature measurement will also be developed and tested in NETL's turbine laboratory.

Relationship to Program:

This project will support important advances in monitoring and control within the Advanced Gasification area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

As new technologies for coal-fired power plants for advanced power generation emerge, integrated gasification combined cycle (IGCC) plants offer the potential to be competitive with all other power systems from a cost and performance standpoint; however, for electric power generation, the technology remains in the demonstration phase. Although coal gasification has been successfully demonstrated to produce fuels, chemicals, and fertilizers in refineries and chemical plants, process improvements must be made to reduce cost and optimize performance. To optimize performance for these IGCC plants, certain important physical parameters should be monitored and precisely controlled within the coal gasification processes, such as temperatures at various locations in a coal gasifier. Through improved operating efficiency and reduced downtime, the harsh-environment temperature sensors developed under this project have the potential to bring the cost of IGCC power generation more in line with conventional coal-fired techniques.

Primary Project Goal:

The focus of this research program is the development of a temperature measurement system for slagging coal gasifiers. Goals of the project include identification of a set of materials sufficiently robust for the environment; development of a viable optical-based approach for temperature measurement; and development of a sensor design, including packaging, that integrates with a full-scale gasification vessel. Goals for demonstrating the developed techniques have been incremental in nature, including laboratory demonstration, demonstration of the design(s), initial performance demonstration on a full-scale gasifier, and a demonstration that evaluates the commercial viability of the approach for coal gasification applications. The viability of this approach for other harsh environments will be determined through bench-scale testing on a turbine combustion system.

Objectives:

Phase I: (10/01/99–04/31/02)

The goals of this project were to design, construct, and test an optically based temperature sensor capable of operating accurately and reliably within the harsh conditions of a coal gasifier. The feasibility of the proposed BPDI temperature sensor, using single-crystal sapphire, was demonstrated in the laboratory. Using the basic design of the BPDI sensor and operational requirements for a specific coal gasification facility, a ruggedized sensor and protective housing were designed. The system was evaluated and calibrated in the laboratory. The temperature measurement system was evaluated by Global Energy Technology's Wabash Gasification facility, including the potential for field-testing.

Phase II: (05/01/02–08/31/09)

The focus of this phase of the project was to redesign the sensor for more viable integration with an entrained flow gasifier followed by evaluation of the sensor at full scale. In contrast to the bulk-optical BPDI sensor developed in Phase I, the fiber-based approach, which relies on a sapphire wafer tip as the sensing element, is proposed to realize a more compact, robust design. The proposed program builds directly on several key technologies developed at Virginia Tech, including a novel white-light interferometry data processing algorithm, silica-to-sapphire fiber connectorization, and sapphire wafer based Fabry-Perot interferometry with a high-interference fringe contrast. Iterative field testing of the developed sensor was performed in the coal gasification facility at TECO, in Tampa, Florida. Results of the field test process were used to generate recommendations for future sensor development and improvement.

Phase III: (09/01/09–08/31/12)
The objective of this Phase III effort is to demonstrate the full capability of an integrated sapphire optical temperature sensor through the development of sapphire-based sensor assemblies and performance evaluation of the sensor on a full-scale coal gasifier and a bench-scale aerothermal turbine combustion rig. For evaluation of the sensor's performance and commercial viability, Virginia Tech will partner with Eastman Chemical to conduct full-scale testing at Eastman's Kingsport, Tennessee gasification facility. Collaboration with NETL's Office of Research and Development will also enable evaluation of sensor performance when placed in a bench-scale combustion turbine environment.

10: OSAP-401.01.13

Project Number OSAP-401.01.13	**Project Title** GHG Reductions in the Power Industry Using Domestic Coal and Biomass			
Contacts DOE/NETL Project Mgr.	**Name** Michael Matuszewski	**Organization** NETL-OSAP	**Email** Michael.Matuszewski@NETL.DOE.GOV	
Principal Investigator	Michael Matuszewski	NETL-OSAP	Michael.Matuszewski@NETL.DOE.GOV	
Partners	RDS Parsons			
Stage of Development				
__ Fundamental R&D	X Applied R&D	__ Proof of Concept	__ Prototype Testing	__ Demonstration

Technical Background:

This study explores the carbon reduction benefits and economic outcome of supplementing the coal feed to state-of-the-art integrated gasification combined cycle (IGCC) power plants with a biomass fuel. Combusting biomass grown for gasifier feed is considered carbon-neutral because the CO_2 combustion product emitted to the atmosphere is offset by the biomass feed during the growth process. However, the cultivation, harvesting, and delivery of biomass produces emissions not offset by biomass growth and so must be considered when evaluating life-cycle greenhouse gas (GHG) emissions. Similar life-cycle emissions for coal are also considered.

This study reports results for a nominal 550 megawatt (MW) dry-fed, entrained flow, combined cycle gasification system incorporating a conceptual dual-stage Selexol system for CO_2 capture. There are two site locations assumed for this biomass gasification study:

- 0 ft of elevation (International Standards Organization [ISO] conditions) co-fired with Illinois #6 coal
- 3,400 ft of elevation co-fired with Powder River Basin (PRB) coal

All studies are performed with the same set of technical, financial, and environmental assumptions, where appropriate, for a proper comparison.

Results

This report reveals potential synergies between the economics of coal-based power generation and the CO_2-neutrality of biomass. This study found that, in light of potential carbon legislation, reasonably low GHG taxes can make co-firing with biomass a cost-competitive means to reduce GHG emissions for power generation. Not only will this minimize the cost to reduce emissions in the event a carbon tax is passed, this technology has the potential to enhance energy security by expanding the options for alternative domestic feedstocks, preserving our nation’s coal supply.

Relationship to Program:

This cost-benefit study supports advances in biomass co-gasification for the engineering analysis focus area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program, highlighting process design and logistical bottlenecks that can create opportunities for research and development.

This study uncovered concerns with the limitations of available biomass, specifically switchgrass, for co-feed into large-scale power plants. The technical success of this carbon mitigation strategy has prompted further work in characterizing the availability of switchgrass and other potential biomass feedstocks. This study also forced consideration of the effects certain biomass impurities may have on fouling/slagging/operational issues in the plant, including feeding difficulties. NETL is already using this study for guidance in solving these types of issues.

Primary Project Goal:
The objective of this study is to determine the technical, economic, and environmental sensitivity of an IGCC system to the introduction of varying quantities of biomass feed to meet pre-determined GHG emission targets. System economics are also adjusted and compared at varying levels of GHG taxes.

Objectives:
Forty-seven total system studies were performed to address the following project objectives:

1. Determine technical and economic benefits of adding strategic levels of biomass feedstock to achieve net zero life-cycle GHG emissions in an IGCC power plant.
2. Determine the technical and economic benefits of adding strategic levels of biomass feedstock in an IGCC power plant to achieve GHG emission levels matching or closely representing: California's GHG emission performance standard (1,100 lb CO_2/net-MWh), a state-of-the-art natural gas combined cycle (NGCC) plant (800 lb CO_2/net-MWh), and an IGCC plant (350 lb CO_2/net-MWh) with 90% CO_2 capture.
3. Quantify economy-of-scale limitations of a 100% biomass IGCC power plant, and the economic benefits of co-feeding coal.
4. Determine the technoeconomic performance and life cycle GHG emissions of a state-of-the-art IGCC power plant that employs full (~90%) CO_2 capture while also co-feeding biomass.
5. Determine whether Carbon Capture and Storage (CCS) or biomass co-feeding is economically preferred to achieve very low levels of CO_2 capture in an IGCC power plant.

11: ORD-10-220615.1, ORD-10-220663.9

Project Number ORD-10-220615.1, ORD-10-220663.9	**Project Title** Fuel Flexible Advanced Energy Systems for the Production of Syngas			
Contacts DOE/NETL Project Mgr.	**Name** George Richards	**Organization** NETL-ORD	**Email** George.Richards@netl.doe.gov	
Principal Investigator	Bryan Morreale	NETL-ORD	Bryan.Morreale@netl.doe.gov	
Partners	Dirk Van Essendelft, Chris Guenther, Ping Wang, and David Berry			
Stage of Development				
_X_ Fundamental R&D	__Applied R&D	__ Proof of Concept	__ Prototype Testing	__Demonstration

Technical Background:

Through the fuel flexible advanced energy systems for the production of syngas research program, DOE/NETL has begun a detailed and broad study with the goal of understanding how to best use plant-based biomass (hereafter referred to as "biomass") with coal in gasification technologies for energy production. Biomass can be thought of as chemically stored solar energy and represents a large potential carbon-neutral energy source (except for carbon used in growing and harvesting the biomass). The substitution of biomass for coal in energy applications could result in a significant carbon footprint reduction and even a negative carbon footprint, if combined with carbon capture and storage.

Even though biomass represents a tremendous resource, using biomass with coal to any significant percentage is not a trivial issue, and there are many knowledge gaps. Biomass is not a great fuel in its natural form. It contains high moisture, has a low energy density, is prone to biodegradation, contains high amounts of oxygen, and has low thermal degradation temperatures and poor material handling properties. Compared to direct combustion, co-gasification is still a very young science, and only a tiny fraction of the research in gasification has been conducted on biomass co-gasification. As a result, little is known regarding how biomass will behave in an industrial gasification system and what the impacts will be on system performance. This program will begin efforts to address the knowledge gaps, gain real-world operation experience, determine best practices, and make recommendations for industry and future work.

To accomplish this goal, NETL has adapted a multi-division, multi-organizational strategy with the intent to organize what had been several relatively small independent research efforts into one large effort to develop real, industrially relevant experimental and process data that will support detailed computational models and systems analysis with a variety of feedstocks, treatment strategies, and operational scenarios. Within NETL, this research effort spans six divisions. Outside of NETL, partnerships exist or are in the process of being developed with at least two universities and five corporations (and this number is growing).

The research has been divided into five tasks:

1. Preprocessing and feeding: The objective of this task is to improve fuel quality, energy density, and material handleability by processing the biomass in some fashion before using it as a fuel. To accomplish this, NETL will identify, develop, and obtain experimental data on promising preprocessing technologies such as

torrefaction, slow pyrolysis, compaction/dewatering, and supercritical dissolution as well as determine performance and additional processing necessary for various pressurized, dry gasification feed strategies.

2. Refractory life and materials: The objective of this task is to identify and address materials compatibility and life issues that arise from adding new compounds to the gasifier that are present in biomass. ***This task is covered under separate review.***
3. Gasification kinetics: The objective of this task is to determine kinetic expressions for raw and treated biomass under high heating rate gasification conditions. The same feedstocks used in the preprocessing and feeding subtask will be used here. The information generated will be incorporated in the computational gasification modeling subtask and help determine feed requirements for the preprocessing and feeding subtask.
4. Computational modeling: The objective of this task is to model and validate real gasifiers with raw/treated biomass and biomass-coal blends. Computational modeling has led to greater understanding of gasification processes and better and more optimized design with reduced costs and development time. ***This task is covered under separate review.***
5. Systems analysis: The objective of this task is to integrate all of the detailed information generated in the first three subtasks to test various biomass utilization strategies and predict real costs, energy efficiencies, true carbon savings, and logistics issues. With this information, NETL will be able to make sound recommendations for best practices and cost-effective biomass utilization and carbon reduction. ***This task is covered under separate review.***

Relationship to Program:

This project supports important technical advances in biomass co-gasification for the advanced gasification focus area of DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

The fuel flexible advanced energy systems for the production of syngas research program will define the minimum energy penalty connected with preparing the most common types of biomass for successful use with coal in co-gasification. These data will enable gasification operators to evaluate the equipment and energy needed to add biomass to existing gasification applications and design new systems. Further, this project will result in a greater knowledge of individual and independent technologies and how to best use them in concert to supply biomass for co-gasification at the lowest and highest efficiency.

This research effort will undoubtedly result in information that is of value to co-firing applications and for applications based on 100% biomass utilization. However, the program focus is strictly on the co-gasification of biomass and coal and the associated technical challenges.

Primary Project Goal:

The overall goal of the fuel flexible advanced energy systems for the production of syngas research program is to identify, understand, and address the technical and logistical challenges involved in utilizing biomass in conjunction with coal in gasification applications and to make recommendations for best practices to U.S. industry so that energy can be produced domestically with a significantly reduced or negative carbon footprint.

Objectives:

Note: Only tasks funded under ORD-10-220615.1, ORD-10-220663.9, and ORD 10-1610238.675 are discussed.

Preprocessing and Feeding Task

The objectives include the following:

1. Select biomass materials: A survey of biomass availability and quantity will be completed. Five biomass samples will be selected based on a scoring system.
2. Arrange for industrial treatment: Through the mechanism of a cooperative research and development agreement, several companies have approached NETL with interest in being part of the developed program. Integro Earthfuels, Alterna Biocarbon Inc., and EARTH Corp have agreed to let NETL have access to their pilot facilities to take process measurements while treating tons of the materials selected in objective 1. The three companies have agreed (or are in the final stages of formal contract development) to allow NETL to have access to their facilities to gather information while the biomass is being processed. Then, NETL will incorporate their materials in the material assessment plan and feeding evaluation.
3. Procure and install specialized equipment: Any equipment not already owned or contracted for will be purchased and installed so that objectives 4 and 5 can be completed. Specifically, this includes a customized Prater Industries MM5 hammer mill system, a Sympatec QICPIC particle size and shape analyzer, a Temco FCHT core holder (for making high-pressure permeability and friction angle measurements), and several other small pieces of equipment.
4. Contract with Universities for Testing: West Virginia University (WVU) will be conducting approximately 750 microindentation tests for NETL. This information will lead to a correlation between the micromechanical properties of heat-treated biomass and the grinding energy required to produce a certain-sized material. In addition, NETL will submit samples to WVU for analysis of energy content and proximate/ultimate analysis. Penn State University (PSU) has all of the supporting equipment needed to run the Temco cell and make high-pressure friction angle measurements. An agreement is being formed between PSU and NETL for this testing.
5. Material chemical/physical characterization: Once materials are procured, they must be characterized. These characterizations include cellulose, lignin, hemicellulose, and xylan content; impurity analysis; water content; ash content and composition; thermal gravimetric analysis; scanning electron microscopy, QICPIC size and shape analysis, Fourier transform infrared (FTIR) response, bulk and true density measurement, large-scale grindability tests, and sieve size analysis.

Gasification Kinetics Task

The objectives include the following:

1. *Coal-biomass interactions during high-temperature pyrolysis*: Previous results have shown that the practical results of co-feeding coal and biomass during pyrolysis deviates from expected values, based on the combination of pure species. The objective will be to investigate the effect of solid biomass interactions (catalytic) and gaseous biomass product interactions on coal during pyrolysis.
   - 1.1 Investigate the influence of alkali and alkaline earth metals, present in solid biomass product, on the pyrolysis of coal. Initial inductively coupled plasma optical emission spectrometry (ICP-OES) analysis results show that biomass ash contains significant quantities of alkali and alkaline earth metals. These metal ions are known for catalytic activity in coal pyrolysis and gasification. Catalytic activity testing will begin by physically mixing quantities of biomass ash with coal as a feed during pyrolysis.
   - 1.2 Investigate the influence of gaseous products (gases produced from the rapid pyrolysis of biomass) on the pyrolysis of coal. Gases such as hydrogen, water, and carbon dioxide are well known to alter the thermochemical conversion of coal. This may be verified by testing with inert sweep gas mixed with a product gas component. Alternatively, this effect can be determined by testing with biomass samples that have undergone a range of thermal pretreatments, including no pretreatment (wet biomass), drying, torrefaction, and pre-pyrolysis, each with successively smaller volatile matter content.
2. *The influence of operating parameters on high-temperature pyrolysis:*
   - 2.1 Investigate the effect of major operating parameters on pyrolysis rate: pressure, biomass feedstock, feed pre-processing, and particle size. Testing would be done on various coal and biomass mixtures under different temperature, pressure, and particle size conditions. In addition, the biomass feedstock handling processes considered may include drying, compression, torrefaction, and pre-pyrolysis, and washing of the feedstock to remove alkali metals.
   - 2.2 Testing will be done to provide a comparison with at least one other biomass. Biomass sources are so different in nature that multiple biomass samples will be investigated in addition to switchgrass. This may include sources such as corn stover and algae. This will be done to complete a matrix of coal/biomass mixes, plus the effects of temperature, pressure, biomass feedstock pre-processing, and particle size.
3. *Low-temperature co-gasification:* Research will transition from pyrolysis to gasification. This will essentially repeat the pyrolysis study (to create a matrix of coal/biomass mixes for two biomass sources, plus the effect ofs temperature, pressure, biomass feedstock pre-processing particle size), plus the effect of steam partial pressure in feed. Work will address the way that the addition of steam changes the interaction between biomass and coal observed during pyrolysis.
4. *Equipment modification:*
   - 4.1 Establishing repeatable and precise kinetic expressions using a semi-batch mode of operation is challenging. Therefore, this sub-objective will be used to develop a steady-state feed system (~20 g/hr) and effluent solid removal for the current reactor system. A steady-state approach would also increase the ability to conduct detailed analysis of the products evolving from the reactor system.
   - 4.2 The current test rig has the capability of operating at temperatures up to 1,000°C, which is consistent with the low-temperature, moving bed

gasification. However, interest in gasification has moved toward entrained conditions. Therefore, the focus of this objective will be to expand the current operating envelope of the reactor system to 1,500°C and 1,000 pounds per square inch.

12: ORD-09-220677-T02

Project Number ORD-09-220677-T02	**Project Title** Dynamic Simulation and Control of Advanced Power Generation Systems			
Contacts DOE/NETL Project Mgr.	**Name** Stephen Zitney	**Organization** NETL – ORD	**Email** steve.zitney@netl.doe.gov	
Principal Investigator	Stephen Zitney	NETL – ORD	steve.zitney@netl.doe.gov	
Partners	West Virginia University, Chemical Engineering - Morgantown, WV Enginomix - Menlo Park, CA Fossil Consulting Services (FCS) - Columbia, MD Invensys Operations Management (IOM) - Carlsbad, CA; Houston, TX Electric Power Research Institute (EPRI) - Charlotte, NC; San Francisco, CA			
Stage of Development				
_ Fundamental R&D	__ Applied R&D	__ Proof of Concept	_X_ Prototype Testing	__ Demonstration

Technical Background:

Integrated gasification combined cycle (IGCC) is emerging as an attractive technology option for providing clean, low-cost electricity for the next generation of coal-fired power plants, and will play a central role in the development of high-efficiency, zero-emissions power plants. As a result, DOE has established a 2012 program goal to design and operate advanced IGCC technology capable of capturing 90% of the carbon dioxide (CO_2) generated at a less than 10% increase in the cost of electricity. To help meet increasing industry and DOE needs for experience with the design, operation, and control of commercial-scale IGCC plants, this project is aimed at developing and deploying a full-scope, high-fidelity, real-time dynamic simulator for an IGCC plant with CO_2 capture. This IGCC operator training system (OTS) will be combined with an immersive training system (ITS); together, they will be capable of training plant engineers and outside field operators in, at a minimum, IGCC plant start-up, shutdown, normal and faulted operations, and safety and risk analysis. Another key goal of this project is to use the IGCC OTS/ITS technology to establish a world-class Dynamic Simulator Research & Training (DSR&T) Center at NETL in Morgantown, WV and a satellite location at West Virginia University's (WVU) National Research Center for Coal and Energy (NRCCE). While the DSR&T Center will be focused initially on IGCC with carbon capture, the long-term plan is for the Center to offer a portfolio of OTS/ITS simulators for advanced energy plants.

The DSR&T Center will be established and operated under the auspices of NETL's Collaboratory for Process & Dynamic Systems Research, a major research thrust area in NETL's Institute for Advanced Energy Solutions with WVU, Carnegie Mellon University, the University of Pittsburgh, Penn State University, and Virginia Polytechnic Institute and State University. Other key collaborative partners include: Invensys Operations Management (IOM), a process simulation and services vendor; Fossil Consulting Services, a consulting company providing engineering and training services to the fossil energy and process industries; Enginomix, a process modeling and simulation consulting company; and the Electric Power Research Institute (EPRI), an independent, non-profit company performing research, development, and design in the electricity sector. Five industry members of EPRI's CoalFleet program are also participating in the project and will receive executable versions of the IGCC dynamic simulator. These five members are American Electric Power, British Petroleum Alternative Energy, Doosan Heavy Industries and Construction Co., Ltd., Great River Energy, and Southern Company.

The overall project work plan for the initial IGCC dynamic simulator consists of eight overlapping phases for the development and deployment of the IGCC OTS/ITS technology and the establishment of the DSR&T Center. The scoping study (Phase I) and detailed planning and specification development (Phase II) were completed in fiscal year 2008. This budget period, FY 2009, covered the first year of IGCC dynamic simulator development (Phase III), which is expected to be deployed in mid- to late-FY 2010 (Phase IV). It also included some early infrastructure development activities to establish the DSR&T Center at NETL and WVU NRCCE (Phase V), as well as some of the planning and development for the functional design specification (FDS) of the IGCC ITS (Phase VI).

Phase I:	OTS scoping study (Complete: DOE/NETL-2008/1321)
Phase II:	OTS planning/FDS (Complete)
Phase III:	Development of IGCC dynamic simulator/OTS (In Progress)
Phase IV:	Deployment of IGCC simulator/OTS at DSR&T Center
Phase V:	Establishment of DSR&T Center (In Progress)
Phase VI:	ITS planning/FDS (Complete)
Phase VII:	Development of IGCC ITS
Phase VIII:	Deployment of IGCC ITS at DSR&T Center

The IGCC dynamic simulator developed in this project will build on and reach beyond existing combined-cycle and conventional-coal power plant simulators to combine, for the first time, a gasification-with-CO_2- capture process simulator with a combined-cycle power simulator in a single simulation framework. The initial commercial-scale IGCC plant design selected for this project is based on slurry-fed, entrained-flow gasification technology with CO_2 capture, advanced F-class combustion turbines, and a triple-pressure heat recovery steam generator/steam cycle. The DOE/NETL report *DOE/NETL IGCC Dynamic Simulator Research and Training Center, Volume 2: IGCC Process Descriptions, June 30, 2008 (DOE/NETL-2008/1324)* provides a conceptual design of the DOE/NETL IGCC Dynamic Simulator reference plan.

A simulation software and services company, IOM, and other partners are working with NETL to develop the IGCC with CO_2 capture dynamic simulator. The simulator development contract was awarded to IOM in a competitive bidding process at the end of FY 2008, and IOM is scheduled to deliver the simulator mid-year 2010 for deployment at NETL and WVU NRCCE in Morgantown, WV. The IGCC simulator is being built using IOM's DYNSIM™ dynamic process simulation software and InTouch™ human-machine interface (HMI) software, as well as their SIM4ME™ technology for providing the integration functionality and performance required for real-time training in IGCC and carbon capture operations and control.

The DSR&T Center will offer much-needed training on the operation and control of IGCC systems with CO_2 capture. Training courses will cover normal IGCC operation, plant start-up, shutdown, load following and shedding, response to fuel and ambient condition variations, and control strategy analysis. Potential users include utilities, engineering firms, technology suppliers, DOE system analysts and engineers, the university engineering and training research and development

(R&D) community, and others interested in learning more about IGCC plant operations and control.

The Center will also provide a world-class resource for advanced IGCC R&D activities in collaboration with university and industry partners. Initial R&D in high-fidelity dynamic modeling is focused on gasification, elevated-pressure air separation units, dual-stage Selexol for hydrogen sulfide (H_2S) and CO_2 recovery, and Claus plants for sulfur capture. Research is also being conducted on strategies for generating fast, dynamic, reduced-order models for use in real-time training applications. Advanced process control research is concentrated on developing model predictive control techniques to determine set points for controllers in the dynamic simulator.

Virtual engineering R&D activities are focused on the development of a 3-D, interactive ITS for use with NETL's IGCC dynamic simulator. The ITS will provide complete IGCC plant emulation in a real-time, 3-D, immersive, navigational, virtual environment by using a link between the IGCC dynamic models and interactive physical-spatial models. It will replicate continuously, in real time and in the virtual environment, complete start-up, throughput changes, and shutdown, as well as IGCC dynamic simulator malfunctions and with changes initiated through actions from the instructor station or from field operators. The system will also have the capability to provide virtual plant interactions for all processes in the IGCC system necessary to support training objectives, including those processes utilizing equipment operated from the control room and/or from the field.

The IGCC dynamic simulator and ITS under development in this project will serve as a world-class tool supporting an extensive research and training program for industry, government, and university personnel in the safe, efficient, and environmentally compatible operation and control of commercial-scale IGCC power plants with carbon capture. In the longer term, it is envisioned that the NETL IGCC simulator may serve as the basis for derivative works/simulators such as a FutureGen plant simulator and customized, plant-specific IGCC simulators for existing and future commercial IGCC plants with carbon capture.

Relationship to Program:

This project will support important advances in simulation and control within the advanced gasification area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

The project brings many benefits to the program, including the following:

- Satisfies an industry need for education and experience with analysis, operation, and control of commercial-scale power generation plants with carbon capture
- Provides NETL's Collaboratory for Process & Dynamic Systems Research with world-class research, training, and education resources, starting with IGCC with carbon capture
- Affords a unique opportunity to collaborate with leading researchers from industry, academia, and government

- Encourages and trains a new generation of engineers in critically needed areas such as the following:
  - Real-time dynamic simulation applications
  - Power plant operations and control
  - Dynamic modeling, advanced process control, and virtual simulation
- Offers a wide range of non-proprietary power plant training courses on IGCC familiarization, operations, and control
- Presents an opportunity to license NETL's generic IGCC simulator for internal training purposes
- Provides a path for derivative works—reducing time, risk, and cost of developing plant-specific IGCC simulators; may serve as a starting point for developing real-time dynamic training for the DOE FutureGen plant
- Accelerates the development of advanced process and dynamic systems modeling technology to better achieve the aggressive goals for design, operability, and controllability of high-efficiency, zero-emission power plants

Primary Project Goal:

The primary goal of this multi-year, multi-phase project is to establish a world-class DSR&T Center starting with the development and deployment of a full-scope, high-fidelity, real-time dynamic simulator/ OTS and ITS for an IGCC plant with CO_2 capture.

Objectives:

Dynamic Simulator/OTS for IGCC with CO_2 Capture

Task 1. Conduct a scoping study. (Complete)

Task 2. Create an NETL FDS for IGCC simulator/OTS. (Complete)

Task 3. Develop the IGCC process and control descriptions. (Complete)

Task 4. Generate a request for proposal (RFP) from NETL FDS and process/control descriptions. (Complete)

Task 5. Release the RFP, evaluate proposals, and award the project. (Complete)

Task 6. Create a detailed vendor-specific FDS for IGCC simulator/OTS. (Complete)

Task 7. Generate an engineering design package for IGCC reference plant. (Complete)

Task 8. Develop and validate a steady-state PRO/II model for the IGCC with CO_2 capture reference plant. (Complete)

Task 9. Complete the design and development of the operator trainee station HMI screens for the IGCC simulator/OTS. (In progress)

Task 10. Generate the operating procedures, malfunctions, and remote functions for IGCC dynamic simulator/OTS. (In progress)

Task 11. Design a control system for IGCC dynamic simulator/OTS. (In progress)

Task 12. Develop and validate a real-time dynamic DYNSIM model for the IGCC with CO_2 capture reference plant. (In progress)

Task 13. Develop an acceptance test procedure (ATP) for the IGCC dynamic simulator/OTS.

Task 14. Complete pre-factory acceptance testing for the IGCC dynamic simulator/OTS.

Task 15. Complete site acceptance testing (SAT) for the IGCC dynamic simulator/OTS.

Task 16. Complete the development of IGCC simulator/OTS documentation.

Task 17. Complete the development of IGCC simulator/OTS training course materials.

Immersive Training System for IGCC with CO_2 Capture

Task 18. Create an NETL FDS for IGCC ITS. (Complete)
Task 19. Generate an RFP from NETL FDS. (Complete)
Task 20. Release the RFP, evaluate proposals, and award the project. (Complete)
Task 21. Create a detailed vendor-specific FDS for IGCC ITS. (In progress)
Task 22. Develop a 3-D virtual model for IGCC with CO_2 capture reference plant.
Task 23. Develop virtual reality functionality including collision geometry, interactive actions/reactions, popup trends, and transparent equipment objects.
Task 24. Integrate a 3-D IGCC virtual engine with IGCC real-time simulator in DYNSIM.
Task 25. Develop an ATP for the IGCC dynamic simulator/ITS.
Task 26. Complete SAT for the IGCC dynamic simulator/ITS.
Task 27. Complete development of the IGCC ITS documentation.
Task 28. Complete development of the IGCC ITS training course materials.

Dynamic Simulator Research & Training Center

Task 29. Develop simulator training infrastructure and facilities at NETL and WVU NRCCE. (In progress)
Task 30. Generate a business plan for DSR&T Center. (In progress)

13: DE-FC26-07NT43094

Project Number DE-FC26-07NT43094	**Project Title** Development of Model Based Controls for GE's Gasifier and Syngas Cooler			
Contacts DOE/NETL Project Mgr.	**Name** Susan Maley	**Organization** NETL – Gasification Division	**Email** Susan.maley@netl.doe.gov	
Principal Investigator	Aditya Kumar	General Electric Global Research	kumara@ge.com	
Partners	GE Global Research GE Energy Tampa Electric Company, Polk Power Station (access to the plant for sensor installation)			
Stage of Development				
__ Fundamental R&D	_X_ Applied R&D	__ Proof of Concept	__ Prototype Testing	__ Demonstration

Technical Background:

Integrated gasification combined cycle (IGCC) plants include a highly integrated chemical plant coupled to power generation and, thus, have a high emphasis on plant efficiency, reliability, availability, and operational flexibility. Current plant operation, however, relies on significant operator experience and manual supervision, due to limited online monitoring and plant-level control and automation. In particular, the core gasification section has an extremely harsh environment, severely limiting online sensors for monitoring and control. As a result, current plant operation is often conservative to ensure safe and reliable operation. This program aims to develop an advanced integrated sensing and controls solution using dynamic model-based technology to enable robust and enhanced IGCC plant operation. Focusing in particular on the gasification section, which is the core section of the plant, the solution will couple limited online sensing with online model-based estimation and constrained dynamic optimization, achieving optimized, robust, and flexible operation while ensuring that all operability constraints are met at all times.

Relationship to Program:

This project will support important advances in the systems monitoring and control focus within the advanced gasification area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

While model predictive control (MPC) has been applied successfully in the chemical process industry, the power generation industry is still largely limited to simple/classical regulatory control. Integrated gasification combined cycle operations, which by definition include an integrated chemical plant upstream of the power generation, have a significant opportunity to benefit from advanced model-based controls at the supervisory section/plant level, allowing optimized and flexible operations that can meet the changing demands of a power generation plant. The developed integrated model-based sensing and control technology will demonstrate the potential for improved plant operation through extensive simulation studies.

Specific improvements for IGCC and other applications include the following:

- Accelerate start-up preheating after a cold shutdown by a potential 20%–25%, increasing overall plant availability.
- Optimize plant operation at baseload with coal as well as coal-petroleum coke (petcoke) blends, achieving high carbon conversion and increased overall efficiency through coordination of multiple control inputs and active management of all operability constraints.
- Accelerate ramp rates during turndown by a potential 20%, allowing enhanced capability for load following that is competitive with other power generation plants.
- Selecting an optimal combination of online sensors in a sensing system where the availability of sensors is limited due to a harsh environment or economic reason is a common problem. The developed model-based analysis approach is generically applicable, addressing common issues of modeling and sensor errors.
- Optimize tracking of controlled outputs (e.g., power outputs) and performance objectives (e.g., maximize efficiency, power output, and carbon conversion; minimize oxygen consumption) subject to constraints in a unified approach.

Primary Project Goal:

The primary goal of this project is to develop an advanced model-based sensing and control solution and demonstrate, through extensive model simulations, significant improvements in steady state and transient operation of an IGCC plant, achieving increased availability, plant efficiency, and operational flexibility. More specifically, the objective is to develop and evaluate an advanced sensing and control solution that will enable enhanced operational flexibility of the core gasification section (e.g., gasifier and synthesis gas [syngas] cooler), including flexible operation with feedstock changes, throughput changes from 50% to 100%, and start-up time reduction by up to 30%, depending on available actuator hardware, safety, and operability margins in the start-up process. In particular, this program will demonstrate fuel flexibility for the operation of the gasification section with different blends of bituminous coal and petcoke. The project will devise and use a systematic model-based analysis and design approach to achieve the objective and provide a foundation for the future development of plant-level control and optimization and advanced monitoring and diagnostics that will contribute to additional improvements in overall plant flexibility and availability.

Objectives:

The major project objectives are as follows:

1. Build a dynamic model of the gasification section for start-up and nominal operation, leveraging available static and dynamic models for individual process units in this section.
2. Perform a systematic model reduction for high-order models capturing spatial variation (e.g., a gasifier model with one-dimensional axial variation) to obtain suitable low-order models that retain high accuracy and are amenable to real-time simulation and the design of model-based estimation and control solutions. These models are implemented in a common platform, Matlab/Simulink, to enable rapid simulation studies and the analysis and design of sensing and control systems.

Specific goals include the following:

1. Install sensors in the radiant syngas cooler (RSC) in the Tampa Electric Company Polk power station IGCC plant to obtain operation data to be used for validation of the RSC model.
2. Develop a sensing system integrating online sensors and model-based online estimation using the extended Kalman filter to measure/estimate all key process variables for monitoring and control. This will entail model-based analysis and design of the sensing system including an optimal choice of online sensors and online adaptation of the dynamic model to address sensing and modeling uncertainties.
3. Develop model-based controls and optimization using MPC to improve steady-state and transient operation of the gasification section during start-up and nominal operation. Initially, MPC with ideal sensing will be used to identify performance improvement entitlement for different nominal and start-up operation modes. Finally, it will be coupled with the developed sensing system to obtain overall integrated sensing and control systems.
4. Demonstrate, using simulation studies, improvements in plant efficiency, availability, and operational flexibility through optimized start-up and daily nominal operations. This encompasses the following:
   4.1 Improve startup preheating transient operation, reducing start-up time by up to 30%, depending on available operability margins.
   4.2 Improve steady-state operation at baseload and part-load operations with coal and coal-petcoke fuel blends, achieving high overall plant efficiency and carbon conversion.
   4.3 Improve turndown ramp rates between baseload and 50% load by up to 20%, improving load-following capability.

14: OSAP-401.01.14

Project Number OSAP-401.01.14	Project Title Cost and Performance Baseline for Fossil Energy Plants – Volume 3: Low Rank Coal and Natural Gas to Electricity			
Contacts DOE/NETL Project Mgr.	**Name** Jeffrey Hoffmann	**Organization** NETL-OSAP	**Email** Jeffrey.Hoffmann@NETL.DOE.GOV	
Principal Investigator	Jeffrey Hoffmann	NETL-OSAP	Jeffrey.Hoffmann@NETL.DOE.GOV	
Partners	RDS Parsons Worley Parsons			
Stage of Development				
__ Fundamental R&D	X Applied R&D	__ Proof of Concept	__ Prototype Testing	__ Demonstration

Technical Background:

Extensive in-house modeling and the completed peer review for the comprehensive *Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity* suggested the next logical step to be an extensive study of coal-to-electric power plants utilizing low-rank coal at western locations. Western coal states are largely at higher elevations than eastern coal states, and the lower air mass at higher elevations negatively affects integrated gasification combined cycle (IGCC) plants more than combustion-based plants. Therefore, the evaluation of technologies at relevant ambient conditions fills a gap in publically available studies that evaluate advanced coal technologies.

Relationship to Program:

This project supports important performance and cost study advances in the engineering analysis focus area of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program.

1. Providing guidance on defining cost and performance benchmarks for state-of-the-art fossil-based electricity generation.
2. Contributing to the development of meaningful FE research and development program goals and providing a credible baseline for comparison of cost and performance improvements resulting from funded research activities.
3. Providing credible cost and performance estimates of near-term fossil-based electricity generation technologies located in the western United States at representative ambient conditions equipped with and without carbon capture and storage (CCS).
4. Providing credible cost and performance estimates to various external stakeholders (policy makers, regulators, industry, nongovernment organizations) that will allow informed policy development.
5. Expanding DOE/NETL modeling capabilities by exploring technologies (KBR Transport Reactor, Siemens dry-feed gasifier, circulating fluidized-bed combustion [CFBC] technologies) not recently modeled or costed by the Office of Systems Analysis and Planning.

Primary Project Goal:

The primary goal of this project is to complete a comprehensive, credible, publicly distributable systems study that estimates performance and cost of advanced fossil-based electric generating technologies utilizing low-rank coals (Powder River

Basin [PRB] and lignite) as well as natural gas at western ambient conditions equipped with and without CCS.

Objectives:

1. Complete cost and performance estimates for IGCC with and without CCS—four oxygen-blown technologies (eight cases) on PRB and two oxygen blown technologies (four cases) on lignite.
2. Complete cost and performance estimates for combustion-based technologies with and without CCS—three technologies (supercritical pulverized coal [PC], ultrasupercritical PC, and CFBC) on both PRB and lignite (six cases).
3. Complete cost and performance estimates for natural gas combined cycle—one at PRB site ambient conditions and one at lignite site ambient conditions (four cases).
4. Create a credible baseline of present state-of-the-art technologies so that the benefits (cost and performance) of advanced technologies can be quantified.

15: DE-NT0004397

Project Number DE-NT0004397	**Project Title** Arrowhead Center to Promote Prosperity and Public Welfare in New Mexico			
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Partners				
Stage of Development				
__ Fundamental R&D	_X_ Applied R&D	__ Proof of Concept	__ Prototype Testing	__ Demonstration

Technical Background:

New Mexico State University/Prosper is a policy-oriented project that links the fossil fuel industry, economic development, and environmental issues in New Mexico. New Mexico is an arid, energy producing state with a low per capita income. The project uniquely links these three issues together to produce viable policy and potential technological solutions to the state's interrelated energy, economic development, and water challenges. The analysis includes economic impact studies and long-range dynamic simulations using state-of-the-art economic modeling software, including IMPLAN and models from Regional Economic Models, Inc.

Relationship to Program:

This project will support important policy advances through the engine analyses pathway of the DOE Fossil Energy/NETL Advanced Integrated Gasification Combined Cycle Program. The Prosper project will advance public understanding of how the fossil fuels industries impact the economic development of New Mexico and related environmental issues, particularly water issues. Technical reports will be disseminated to both policymakers and stakeholders in the fossil fuels industry. This will increase the knowledge available to policymakers so that their decisions can take into account local economies, regulations, and technologies.

Primary Project Goal:

The goal of this research and policy initiative project is to enhance fossil fuel energy production and use in New Mexico. This goal must be achieved in an environmentally progressive manner; include economic research on the interrelationships between fossil fuel energy, the economy, the environment, and the impact of the fossil fuel industry on New Mexico's water resources; and enhance public understanding of the issues.

Objectives:

The primary project objective is to enhance fossil fuel energy production and use in New Mexico to contribute to the economic development of the state and create a strong, vibrant economy that better serves the state's citizens. The project work plan includes the preparation of a series of technical reports and significant outreach activities, including sponsored conferences, stakeholder consultations, and the dissemination of research results. In the first year of the project, it is well established, has yielded technical reports, and is widely known through conference sponsorship and stakeholder consultations.

APPENDIX F: LIST OF ACRONYMS AND ABBREVIATIONS

GLOSSARY

Term	Definition
Feedstock (n)	Raw material required for an industrial process.
Syngas (n)	Gas mixture that contains varying amounts of carbon monoxide and hydrogen. Syngas may be produced by steam reforming of natural gas or liquid hydrocarbons to produce hydrogen, the gasification of coal, biomass, and in some types of waste-to-energy gasification facilities.
Steam reforming (n)	a method of producing useful products, such as hydrogen or ethylene from fossil fuels
Gasification (n)	the process of turning a feedstock such as coal, petcoke, or biomass, etc. into a "syngas" of CO and H_2 that can be used as a fuel or a feedstock

ACRONYMS LIST

Acronym/ Abbreviation	Definition
$(NH_4)_2Se$	ammonium selenide
µm	micrometer
ACS	American Chemical Society
ADM	Archers Daniel Midland
AHT	advanced hydrogen turbine
AIChE	American Institute of Chemical Engineers
AIGCC	Advanced Integrated Gasification Combined Cycle
As	arsenic
ASME	American Society of Mechanical Engineers
ATP	acceptance test procedure
BPDI	broadband polarimetric differential interferometry
BRTD	Board on Research and Technology Development
CCC	Copyright Clearance Center
CCS	carbon capture and storage
Cd	cadmium
CF	capacity factor
CFBC	circulating fluidized-bed combustion
CFD	computational fluid dynamics
Cl	chlorine
cm	centimeter
CO	carbon monoxide
CO_2	carbon dioxide
COE	cost of electricity
COP	ConocoPhillips
COS	carbonyl sulfide
CRTD	Center for Research and Technology Development

Acronym/ Abbreviation	Definition
dB	decibel
DO	direct oxidation
DOE	U.S. Department of Energy
DSR&T	Dynamic Simulator Research & Training
DSRP	direct sulfur recovery process
ECCC	Energy Conversion and Conservation Center
EERC	University of North Dakota Energy and Environmental Research Center
EFPI	extrinsic Fabry-Perot interferometer
EPRI	Electric Power Research Institute
Fe_3O_4	iron oxide
FEED	front-end engineering design
FIR	finite impulse response
FTIR	Fourier transform infrared
FY	fiscal year
g	gram
GHG	greenhouse gas
GTC	Gasification Technologies Council
H_2	hydrogen
H_2O	water
H_2S	hydrogen sulfide
H_2Se	hydrogen selenide
HAZOP	hazard and operability
HCl	hydrochloric acid
HCN	hydrogen cyanide
Hg	mercury
HHV	higher heating value
HMI	human-machine interface
HTDP	high-temperature desulfurization process
IChemE	Institution of Chemical Engineers
ICP-OES	inductively coupled plasma optical emissions spectrometry
IGCC	integrated gasification combined cycle
IGFC	integrated gasification fuel cell
IOM	Invensys Operations Management
ISO	International Standards Association
ISTU	intermediate-scale test unit
ITM	ion transport membrane
ITS	immersive training system
K&C	Knowledge and Community
kg	kilogram
kW	kilowatt
kWe	kilowatt electric
kWh	kilowatt-hour
kWth	kilowatt thermal

Acronym/ Abbreviation	Definition
lb	pound
LED	light emitting diode
LNG	Liquefied natural gas
m	meter
MaGIC	Mild gasification
MM	million, or multimode
MPC	model predictive control
MW	megawatt
MWe	megawatt electric
MWT	moving wall testing
NETL	National Energy Technology Laboratory
NGCC	natural gas combined cycle
NH_3	ammonia
nm	nanometer
NRCCE	National Research Center for Coal and Energy
OCC	Office of Clean Coal
OCT	outlet configuration testing
OFET	outlet force evaluation testing
OFT	outlet flow testing
OMB	Office of Management and Budget
OPT	outlet pressure testing
ORD	Office of Research and Development
OSAP	Office of Systems Analysis and Planning
OTS	operator training system
P	phosphorus
P&IDs	process and instrumentation diagrams
PC	pulverized coal
Petrak	Petrak Industries
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
PRB	Powder River Basin
PSA	pressure swing adsorption
PSD	particle size distribution
psi	pound-force per square inch
psig	pound-force per square inch gauge
PSU	Penn State University
PWR	Pratt and Whitney Rocketdyne Inc.
Q&A	question and answer
R&D	research and development
RAM	reliability, availability, and maintenance
RFP	request for proposal
RSC	radiant syngas cooler

Acronym/ Abbreviation	Definition
RTI	RTI International
S	sulfur
SAT	site acceptance testing
scfh	standard cubic feet per hour
SCI	Süd-Chemie
SCL	syngas chemical looping
Se	selenium
SEP	subscale engineering prototype
SIP	steam-iron process
SO_2	sulfur dioxide
SOFC	solid oxide fuel cell
syngas	synthesis gas
TDU	technology development unit
TECO	Tampa Electric Company
TMS	Technology and Management Services, Inc.
TPC	total plant cost
TPD	tons per day
UCSRP-HP	University of California Sulfur Recovery Process – High Pressure
UOP	Universal Oil Products
WGCU	warm gas cleanup
WGS	water-gas shift
wt%	weight percent
WVU	West Virginia University