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Final Report
2007 Strategic Center for Coal Advanced Power Systems Peer Review Meeting

MEETING SUMMARY AND RECOMMENDATIONS REPORT

Pittsburgh, Pennsylvania
July 16 – 19, 2007

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

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FINAL REPORT
2007 STRATEGIC CENTER FOR COAL ADVANCED POWER SYSTEMS PEER REVIEW MEETING

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VOLUME I. MEETING SUMMARY AND RECOMMENDATIONS

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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, abundant low-cost, domestic energy from coal (including hydrogen) to fuel economic prosperity, strengthen energy security, and enhance environmental quality. To achieve its mission, the Clean Coal program is organized into eight technology programs and an international support program. One of these eight technology programs, administered by the DOE Office of Fossil Energy's National Energy Technology Laboratory (NETL), is the **Advanced Power Systems (APS)**. It is the mission of the APS to develop a new generation of electric power generating "platforms"—employing advanced coal gasification, turbines capable of burning coal-derived syngas, and novel combustion concepts—that will form the core of the "zero" emission coal plant of the future.

The primary objective of the APS Program is to develop advanced coal-based power systems capable of achieving 45–50 percent thermal efficiencies at a capital cost of $1,000 per kW or less by 2010. The APS Program will also capitalize on research progress in other Clean Coal Program areas, including carbon sequestration and fuel cells.

In compliance with the President's Management Agenda for "Better R&D Investment Criteria" and subsequent 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. For the APS Program, DOE and NETL conducted a Peer Review meeting with independent, technical experts to assess ongoing research projects and, where applicable, to make recommendations for improvement.

In cooperation with Technology & Management Services, Inc., the American Society of Mechanical Engineers (ASME) convened a panel of 10 leading government, academic, and industry experts on July 16-19, 2007, to conduct a four-day review of selected APS research projects supported by NETL.

Overview of Advanced Power Systems Research Categories

The Review Panel completed evaluations of 21 projects in the following three APS research categories:

- Coal Gasification 7 projects;
- Advanced Research 3 projects; and
- Advanced Turbines 11 projects.

The total funding for these 21 projects, over the duration of the projects, is $874,194,248, of which $677,399,817 (77%) is from DOE and $196,794,431 (23%) is from cost-sharing. The allocation of DOE funding by sub-program in this review is as follows:

- Coal Gasification $138,257,605 (20.4%)
- Advanced Research $ 59,715,809 (8.8%)
- Advanced Turbines $479,426,403 (70.8%)

The 21 projects that were the subject of this Peer Review are summarized in Table 1 and in Section II of this report.

Overview of the Peer Review Process

NETL requested that ASME assemble a Peer Review Panel of recognized technical experts to provide recommendations on how to improve the performance, management, and overall results from each individual research project. Prior to convening the Review Panel, each project team prepared an 11-page Project Summary Sheet containing summary information about the project, copies of which were subsequently provided to the Review Panel in advance of July 2007 Peer Review Meeting. Based on their review of this information, the individual Panel Members submitted a series of comments/questions. Copies of the Panel's questions were forwarded to the respective Principal Investigators (PIs), and responsible NETL Project Manager, in advance of the meeting. The PI was instructed to address these questions during the formal presentation at the Peer Review meeting. At the meeting, each research team made a 30-minute presentation (or longer, for larger projects) that was followed by a 20-minute question-and-answer session with the Reviewers and a 20-minute group discussion of each project. Each panel member then evaluated all 21 projects using both a predetermined set of review criteria and written review comments. For each of the 10 equally weighted Review Criteria (see page 8), the individual Reviewer was asked to "score" the project as to whether it is:

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

Figure ES-1 shows the overall average score, including all 10 Review Criteria, for all 21 projects.

FIGURE ES-1

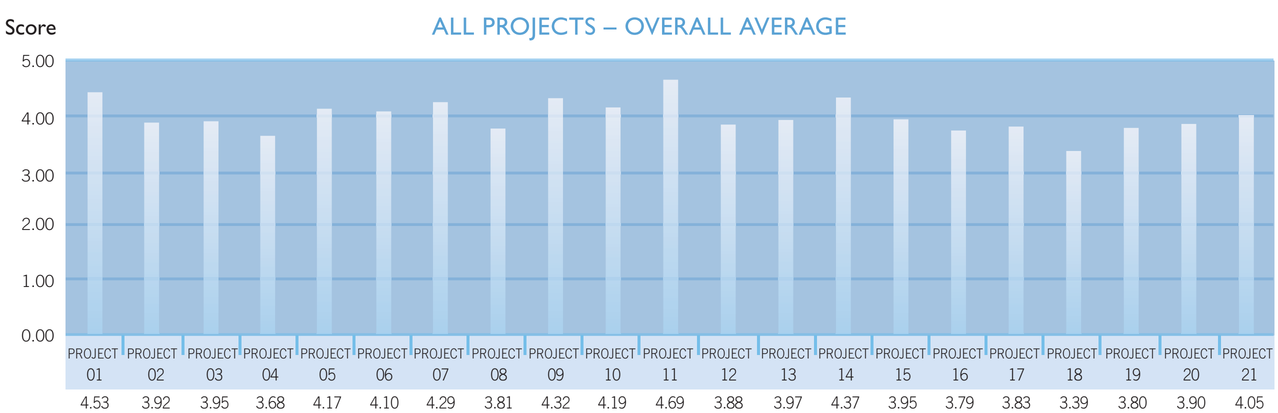


TABLE ES-1 DOE ADVANCED POWER SYSTEMS (APS) PROJECTS REVIEWED

APS Reference Number	Project Number	Title	Lead Organization	Principal Investigator	Total Funding[1]		Project Duration[1]	
					DOE	Other	From	To
01	FT40343	ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems	Air Products and Chemicals, Inc.	Phillip Armstrong	$84,808,293	$62,453,894	30-Sep-98	30-Sep-10
02	FT40675	Novel Technologies for Gaseous Contaminants Control	Research Triangle Institute	Raghubir Gupta	$19,098,213	$5,412,558	15-Sep-99	31-Dec-07
03	NT41866	Hybrid Combustion-Gasification Chemical Looping Coal Power Technology Development	Alstom Power, Inc.	Herbert E. Andrus	$5,194,923	$1,298,730	30-Sep-03	31-Mar-08
04	MC25140	Power Systems Development Facility (PSDF)	Southern Company Services, Inc. - Birmingham, AL	Kerry Bowers	$366,568,332	$60,367,261	14-Sep-90	31-Mar-08
05	NT42469	Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants	Eltron Research & Development, Inc.	Doug S. Jack	$2,332,642	$583,160	16-Aug-05	30-Sep-07
06	ORD-07-22068-1	Refractory Materials For Slagging Gasifiers	National Energy Tech. Laboratory - Albany	Cynthia Powell	$607,000	$0	01-Oct-06	30-Sep-07
07	T401.01.04	2006 Cost and Performance Baseline for Fossil Energy Plants	National Energy Tech. Laboratory - Morgantown	Julianne Klara	$817,000	$0	01-Dec-04[2]	30-Jun-07[2]
08	NT41922	New Optical Sensor Suite for Ultra High Temperature Fossil Fuel Applications	Prime Research, LLC	Russell May	$1,645,275	$141,056	29-Sep-03	31-Dec-07
09	NT41175	Development of Advanced Materials for Ultrasupercritical Boiler Systems	Energy Industries of Ohio	Vis Viswanathan	$19,893,300	$10,245,520	30-Sep-01	31-Dec-09
10	FEAA028	Fossil Energy Advanced Research Materials Program	Oak Ridge National Laboratory (ORNL)	Roddie Judkins	$38,177,234	$0	01-Oct-97	30-Sep-07
11	NT41431	University Turbine Systems Research (UTSR) Program	South Carolina Institute for Energy Studies	Robert Leitner	$14,589,002	$1,311,100	20-Mar-02	31-Dec-08
12	NT42643	Advanced IGCC/Hydrogen Gas Turbine Development	GE Energy Inc.	Kevin Collins	$45,774,419	$19,617,608	30-Sep-05	30-Sep-12
13	NT42644	Advanced Hydrogen Turbine for FutureGen	Siemens Power Generation - Orlando	Joseph Fadok	$45,518,250	$18,877,045	30-Sep-05	30-Sep-12
14	NT42650	Novel Concepts for the Compression of Carbon Dioxide	Southwest Research Institute	Klaus Brun	$175,033	$43,759	28-Sep-05	31-Mar-08
15	NT42651	CO2 Compression Using Super Sonic Shock Wave Technology	Ramgen Power Systems	Pete Baldwin	$9,494,546	$6,614,665	10-May-06	09-Jan-11
16	ORD-07-220623-2	Combustion Systems for Hydrogen-Based Turbines	National Energy Technology Laboratory-MGN	Kent Casleton Pete Strakey	$873,000	$0	01-Oct-06	30-Sep-07
17	NT42646	Zero Emissions Coal Syngas-Oxygen Turbo Machinery	Siemens Power Generation - Orlando	Mohan Hebbar Jim Downs	$15,701,507	$6,114,314	30-Sep-05	30-Sep-11
18	NT42645	Coal-Based Oxy-Fuel System Evaluation and Combustor Development.	Clean Energy Systems, Inc.	Scott MacAdam	$4,407,837	$3,522,008	30-Sep-05	30-Sep-08
19	NT42652	Systems Analysis of Advanced Brayton Cycles	UC Irvine	Scott Samuelsen	$767,011	$191,753	29-Sep-05	30-Sep-07
20	FWP FEAA070	Materials Issues in Coal-Derived Synthesis Gas/Hydrogen-Fired Turbines	ORNL	Ian Gordon Wright	$922,000	$0	01-Oct-04	30-Sep-07
21	T401.01.06	Development of Baseline Performance Values for Turbines in Existing IGCC Applications	National Energy Technology Laboratory	Walter Shelton	$35,000	$0	01-Feb-06[2]	01-Nov-06[2]
				TOTALS	**$677,399,817**	**$196,794,431**		

Notes:
[1] All funding amounts and project durations obtained through ProMIS on 8-21-07, except where noted (T401.01.04 and T401.01.06)
[2] Funding amounts and project durations obtained from project summaries submitted by the Principal Investigator.

Table ES-2 shows the overall average, highest individual, and lowest individual score given for each Review Criterion, rank ordered from highest to lowest average score, across all 21 projects reviewed.

TABLE ES-2. SCORES BY REVIEW CRITERION

Rank	Criterion	Average	Highest	Lowest
1	Scientific and Technical Merit	4.3	5.0	3.7
2	Technical Approach	4.3	5.0	3.7
3	Utilization of Government Resources	4.2	5.0	3.7
4	Anticipated Benefits if Successful	4.2	4.9	3.5
5	Rate of Progress	4.1	4.8	3.4
6	Commercialization Potential	4.1	4.8	3.4
7	Knowledge of Related Research	4.0	4.7	3.3
8	Attention to Constituent Group Concerns	3.9	4.9	3.3
9	Possible Adverse Effects Considered	3.7	4.2	3.0
10	Economic Analysis	3.4	4.3	2.4

For more on the overall evaluation process and the 10 Review Criteria, see Section III.

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 Project Manager, José D. Figueroa, at (412) 386-4966 or Jose.Figueroa@netl.doe.gov.

I. INTRODUCTION

In 2007, the American Society of Mechanical Engineers (ASME) was invited to provide an independent, unbiased, and timely review of selected projects within the Advanced Power Systems (APS) Program in the U.S. Department of Energy (DOE), Office of Fossil Energy. This report contains a summary of the findings from that review.

Compliance with OMB Requirements

The peer review of selected projects within the APS Program has been designed to comply with requirements from the Office of Management and Budget (OMB) concerning the President's Management Agenda and specifically to address the requirement for "Better R&D Investment Criteria." The DOE, the Office of Fossil Energy, and the National Energy Technology Laboratory (NETL) are fully committed to improving the quality and results of their projects.

ASME was selected as the independent contractor to review 21 projects in the following three APS research categories:

- Coal Gasification 7 projects;
- Advanced Research 3 projects; and
- Advanced Turbines 11 projects.

ASME performed this project review work as a subcontractor to Technology & Management Services, Inc. (TMS), a DOE prime contractor. The 21 projects reviewed were selected by NETL. They are reported to represent >80% (on a $ basis) of the APS portfolio. Principal Investigators (PIs) submitted an 11-page written summary of their projects, received questions from Review Panel Members prior to the review meeting, and then made an oral presentation to the Panel selected and convened by ASME. ASME conducted the review meeting, including an evaluation of each project against predefined criteria. Results of the review and a general overview of findings are presemted in this document.

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 selecting all Review Panel members and ensuring there are no conflicts of interest within the Panel or the review process. In consultation with NETL, ASME is responsible for formulating the review meeting agenda, providing information advising the PIs and their colleagues on how to prepare for the review, facilitating the review session, and preparing a summary of the results. A more extensive discussion of the ASME Peer Review Methodology used for the APS Peer Review Meeting is provided in Appendix A. A copy of the Meeting Agenda is provided in Appendix B, and an introduction to the Peer Review Panel members for this APS Peer Review is provided in Appendix C.

Peer Review Criteria and Peer Review Criteria Forms

ASME developed a set of agreed-upon review criteria to be applied to the projects under review at this meeting. The review criteria were provided to the Review Panel and PIs in advance of the Peer Review Meeting and pre-loaded (one for each respective project) onto laptop computers for each panel member to facilitate the review process at the Peer Review Meeting. During the Peer Review Meeting, the Panel Members assessed the strengths and weaknesses for each project before providing both recommendations and action items, and completed the review criteria forms in closed sessions. 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 APS Peer Review Meeting and are organized as follows:

II. Summary of Projects Reviewed in 2007 APS Peer Review
    A summary description of the 21 projects reviewed.

III. An Overview of the Evaluation Process in 2007
    A brief overview of evaluations along with analysis and recommendations.

IV. Summary of Key Project Findings
    A summary of key findings gained by looking across all 21 projects.

V. Process Considerations for Future Project Reviews
    A few lessons learned in this review that could be applied to future reviews.

II. SUMMARY OF PROJECTS REVIEWED IN 2007 APS PEER REVIEW

The projects that were reviewed by the independent ASME Review Panel for the Advanced Power Systems (APS) Peer Review were selected by NETL. NETL used the criteria listed below to select the set of projects within the APS Program for review.

- Key projects within the Gasification, Turbines, and Advanced Research Technology Programs and related projects being conducted in NETL's Office of Research and Development (ORD) and Office of Systems Analysis and Planning (OSAP).
- Projects that have been active for at least 12 months (i.e., would have conducted sufficient work to be evaluated).
- Projects that have at least 12 months of performance remaining (i.e., sufficient time remaining to benefit from Peer Review comments/recommendations).
- Collectively, the set of projects represent 80-90% (on a $ basis) of the APS Program portfolio—consistent with DOE/EERE **Peer Review Guide** (August 2004) for conducting peer reviews.

The 21 projects were reviewed in two sessions. In Session I, projects within the Gasification and Advanced Research Technology Programs (and associated NETL-ORD and NETL-OSAP projects) were reviewed. During Session II, projects within the Turbines Technology Program (and associated NETL-ORD and NETL-OSAP projects) were reviewed.

SESSION I: GASIFICATION AND ADVANCED RESEARCH

01: DE-FC26-98FT40343

Development of ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems

Air Products and Chemicals, Inc.

02: DE-AC26-99FT40675

Novel Technologies for Gaseous Contaminants Control

Research Triangle Institute

03: DE-FC26-03NT41866

Hybrid Combustion-Gasification Chemical Looping Coal Power Technology Development

Alstom Power, Inc.

04: DE-FC21-90MC25140

Power Systems Development Facility (PSDF)

Southern Company Services – PSDF

05: DE-FC26-05NT42469

Scale-up of Hydrogen Transport Membranes for IGCC and FutureGen Plants

Eltron Research & Development, Inc.

06: ORD-07-22068-1

Refractory Materials for Slagging Gasifiers

National Energy Technology Laboratory

07: T401.01.04

2006 Cost and Performance Baseline for Fossil Energy Plants

National Energy Technology Laboratory

08: DE-FC26-03NT41922

New Optical Sensor Suite for Ultra High Temperature Fossil Fuel Applications

Prime Research, LLC

09: DE-FG26-01NT41175

Development of Advanced Materials for Ultrasupercritical Boiler Systems

Energy Industries of Ohio

10: FEAA028

Fossil Energy Advanced Research Materials Program

Oak Ridge National Laboratory

SESSION II: ADVANCED TURBINES

11: DE-FC26-02NT41431

University Turbine Systems Research (UTSR) Program

South Carolina Institute for Energy Studies

12: DE-FC26-02NT42643

Advanced IGCC/Hydrogen Gas Turbine Development

GE Energy, Inc.

13: DE-FC26-02NT42644

Advanced Hydrogen Turbine for FutureGen

Siemens Power Generation

14: DE-FC26-02NT42650

Novel Concepts for the Compression of Carbon Dioxide

Southwest Research Institute

15: DE-FC26-02NT42651

CO_2 Compression Using Super Sonic Shock Wave Technology

Ramgen Power Systems

16: ORD-07-220623-2

Combustion Systems for Hydrogen-Based Turbines

National Energy Technology Laboratory

17: DE-FC26-02NT42646

Zero Emissions Coal Syngas-Oxygen Turbo Machinery

Siemens Power Generation

18: DE-FC26-02NT42645

Coal-Based Oxy-Fuel System Evaluation and Combustor Development

Clean Energy Systems, Inc.

19: DE-FC26-02NT 42652

Systems Analysis of Advanced Brayton Cycles

University of California at Irvine

20: FWP-FEAA070

Materials Issues in Coal-Derived Synthesis Gas/Hydrogen Fired Turbines

Oak Ridge National Laboratory

21:T401.01.06

Development of Baseline Performance Values for Turbines in Existing IGCC Applications

National Energy Technology Laboratory

A short summary of each of the above projects is presented in Appendix E.

III. AN OVERVIEW OF THE EVALUATION PROCESS IN AND RESULTS

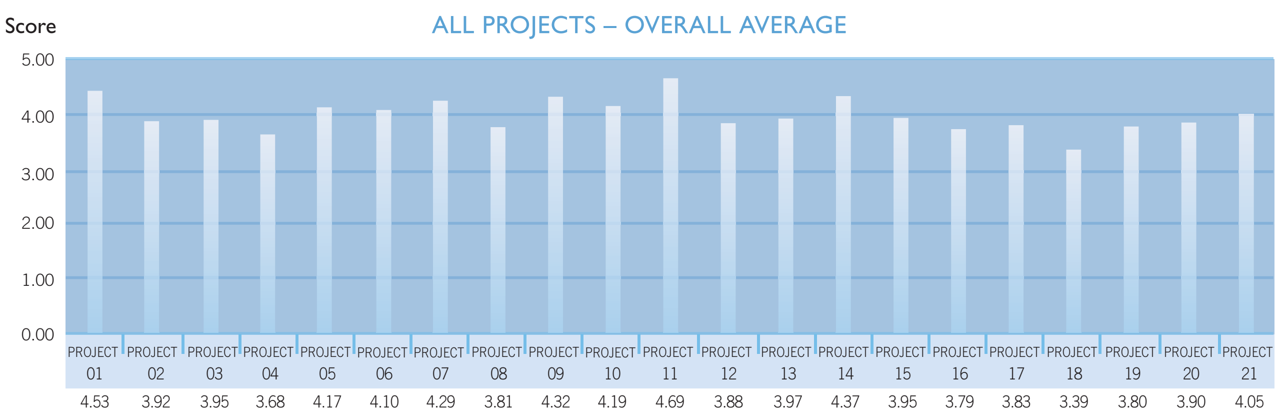
The ASME team, in cooperation with NETL and with input from the Peer Review panel, continues to enhance and refine the process used for evaluating the projects selected for the 2007 APS Peer Review Meeting. A copy of the Peer Review Criteria Form and an explanation of the process are provided in detail in Appendix D.

For each of the 10 Review Criteria, an individual Reviewer is asked to "score" the project as to whether it is:

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

Figure 1 shows the overall average scores across all 10 Review Criteria for each of the 21 projects reviewed in the APS Program. The results are impressive. The range of scores across all projects is relatively narrow, from the lowest overall average score of 3.39—well above "Adequate"—to the highest overall averaged score of 4.69—very close to a perfect "Effective" score of 5.0. Also, the average of these "overall average" scores is 4.02, which is better than "Moderately Effective."

FIGURE 1



It can also be beneficial to look at the average scores for each of the 10 Review Criteria across all 21 projects. The combined average scores for all Review Criteria are shown in Table 2, ranked in order from highest to lowest. Again, it is impressive that the median overall average score for the 10 equally weighted Review Criteria, across the 21 APS projects reviewed, was 4.1, and that on seven out of 10 criteria the score was 4.0 or higher (i.e., "Moderately Effective" or better). The two highest-ranking Review Criteria were "Scientific and Technical Merit" and "Technical Approach," both with an average score across all projects of 4.3.

TABLE 2. SCORES BY REVIEW CRITERION

Rank	Criterion	Average	Highest	Lowest
1	Scientific and Technical Merit	4.3	5.0	3.7
2	Technical Approach	4.3	5.0	3.7
3	Utilization of Government Resources	4.2	5.0	3.7
4	Anticipated Benefits if Successful	4.2	4.9	3.5
5	Rate of Progress	4.1	4.8	3.4
6	Commercialization Potential	4.1	4.8	3.4
7	Knowledge of Related Research	4.0	4.7	3.3
8	Attention to Constituent Group Concerns	3.9	4.9	3.3
9	Possible Adverse Effects Considered	3.7	4.2	3.0
10	Economic Analysis	3.4	4.3	2.4

A blank copy of the Peer Review Criteria Form is provided in Appendix D.

IV. SUMMARY OF KEY FINDINGS

The purpose of this section is to provide a summary of key findings from looking across all of the individual projects considered at the Peer Review. To facilitate the discussion of key issues, this section is divided into two sections, reflecting the two main sessions at the Peer Review.

There was general agreement that all parts of the APS Program (Gasification, Advanced Research, and Turbines Technology programs) are well managed and well focused. The projects seem to be covering the right topics and addressing the right questions that need to be answered. There seems to be a good mix of projects, including short-term data finding as well as some “cutting-edge,” breakthrough projects—a good distribution of projects. As one Reviewer noted, he can see that real progress is being made in the Fossil Energy (FE) program and that NETL’s work is good, and well integrated into the FE program.

Regarding the Gasification program, several Reviewers commented that fostering international cooperation may be in the best interests of the program, especially for work on ultrasupercritical power plants.

Session I: Gasification and Advanced Research

General Project Strengths

The overall quality of projects in the Gasification and Advanced Research sub-programs of the Advanced Power Systems Program was very good. All of the projects reviewed received an average overall score of “Adequate” or better and six of the 10 projects reviewed in this session received an average overall score above 4.0 (out of 5).

Most of the projects in this session scored very well against the review criteria of:

- Scientific and Technical Merit;
- Anticipated Benefits if Successful;
- Technical Approach;
- Rate of Progress;
- Knowledge of Related Research;
- Utilization of Government Resources; and
- Commercialization Potential.

The Peer Reviewers uniformly felt that the projects in this session had done a good job of reaching out to commercial and industrial companies, both large and small, with relevant expertise to the project at hand. Reviewers were generally impressed that the project teams had the necessary core skills, whether in-house or from their partners, to properly address the project’s scope of work.

The projects overall were judged to be well managed and focused. Project teams demonstrated that they knew where they were going, and each PI presentation did a good job of illustrating how that project fit into the overall APS Program.

The work presented on baseline costs and performance for fossil energy plants was given special recognition for its usefulness in helping to set target goals for many projects in the Program and for helping to clear away some of the exaggerated claims that have been made by others outside of the Program.

General Project Weaknesses

Economic Analysis was the Review Criterion against which most of the projects had mixed results. Several of the project teams did not address economics at all. Others did so in a very limited fashion. Although nine of the 10 projects reviewed in this session received an average score of “Adequate” against this criterion, half of those projects received a score of “Ineffective” from at least one Reviewer. Reviewers felt that all of the projects could use some help in regard to economic analysis. It is not necessary, in the opinion of the Reviewers, that all projects, especially early-stage or theoretical research projects, do sophisticated economic analysis. It is important, however, that all projects at least consider the economic implications of applying their research, if successful. The closer a project is to commercialization, the more important this criterion becomes.

Another two areas where Reviewer scores were somewhat lower were in “Considering Possible Adverse Effects” and in “Attention to Constituent Concerns.” As with economics, these criteria are less important for early-stage or conceptual projects and more important for projects closer to commercialization. Many of the projects reviewed had not given enough serious consideration to these issues. Nonetheless, Reviewers felt these criteria must be addressed so that scarce research funding is not spent on projects that could be unacceptable at a later commercialization phase.

Project Issues for Future Consideration

Although most of the projects considered were complimented for having a good command of their own project goals, especially in regard to their individual view of a gasification system, Reviewers felt that the projects needed to integrate better. One Reviewer suggested that all the projects try to agree on a set of uniform process diagrams. This could help to clarify where one project component ended and another began. And all projects should be compelled to do a better job of presenting temperatures and pressures at all points in their component diagrams. Attention to such details would facilitate the review of all projects and clarify their place in the overall system.

Several of the projects reviewed are proposing to send CO_2 or other “outputs” to pipelines for transport to sequestration sites. It was clear from discussions at the meeting that there is a wide divergence of opinion on the likely specifications that pipeline operators will require for these outputs. This should be addressed and provided back to the individual projects for their use.

The University Turbine Systems Research (UTSR) Program review was very well received by Reviewers, in the second session of the Peer Review. Several Reviewers commented that the gasification portion of the APS program could benefit from a similar type of project.

Session II: Turbines

General Project Strengths

The overall quality of all 11 projects reviewed from the Turbine sub-program of the APS program was very good. All of the projects received an overall average score of “Adequate” or better. Three of 11 projects had an overall average above 4.0 (out of 5).

Essentially all of the projects in this session scored very well against the review criteria of:

- Scientific and Technical Merit;
- Anticipated Benefits if Successful;
- Technical Approach;
- Rate of Progress;
- Knowledge of Related Research; and
- Utilization of Government Resources.

One of the turbine projects actually received a “perfect” score of 5.0 for Scientific and Technical Merit—the highest score possible from all 10 Reviewers.

Several of these projects have very long timelines. Nevertheless, Reviewers felt, overall, that the individual project timelines made sense and that they fit well one to another.

The University Turbine Systems Research (UTSR) Program was called out for special commendation, not only because of its generally high quality of management over a wide variety of projects, but also because of its excellent program for training new professionals in a field critical to the future of the United States.

General Project Weaknesses

Many of the projects in this session did not score well against the criterion of “Economic Analysis.” In fact, only six of the 11 projects reviewed received a score of “Adequate” or better. The remaining five projects were judged to be “Ineffective.”

As discussed above, the Reviewers are willing to be flexible in regard to this criterion for projects that are at the very early stages of theoretical investigation. However, in an area like this sub-program, where eventual application is one of the principal targets, economic analysis must be addressed. It has not been done so sufficiently to date.

The lack of economic analysis had a related consequence in that the projects reviewed had a more difficult time of addressing their eventual “Commercialization Potential.” This too needs to be better addressed by these projects.

Finally, project scores for both “Possible Adverse Effects Considered” and “Attention to Constituent Concerns” were inconsistent, indicating that the Reviewers disagreed as to whether or not these criteria had been addressed—suggesting room for improvement.

Project Issues for Future Consideration

The Reviewers were very complimentary that many of the basic questions about future turbine designs were being addressed by various projects in the turbine sub-program. There were some areas, however, where Reviewers felt there were issues of interest or concern that the 11 projects presented were not addressing (but might be addressed in other projects not reviewed):

- Basic interactions of temperature and pressure in high-efficiency turbines still needs to be addressed;
- Will NO_X be manageable in 3,200º F turbines?
- “Real world” concerns about turbine discs and wheels in the proposed new machines have not yet been sufficiently addressed.

Some projects appear to be struggling to balance their own projections of future turbine markets with current DOE target goals. Continuing to integrate technical, market, and economic analysis will help to refine individual project goals.

Lastly in this area of technical research, the future stakes for commercialization are very high. This will make the presentation of technical data very sensitive. While acknowledging the requirement that the PIs not present any proprietary data, all the Reviewers felt that several of the presentations fell short of providing sufficient technical detail. These projects scored lower than they should have because these data were not presented. Future reviews of this sub-program must address this problem early in the meeting planning process.

V. PROCESS CONSIDERATIONS FOR FUTURE PEER REVIEWS

Both Review Panel members and the DOE managers involved in the Peer Review offered constructive comments about how well this review process has worked to date and how it might be modified and improved for the future. Comments were provided both at the conclusion of the sessions on Gasification and Advanced Research projects and again at the end of the Peer Review meeting following the session on Turbines. Following is a brief summary of ideas recommended for use in planning future project review sessions.

General Process Comments

There was unanimous agreement that the Peer Review process as it is currently constituted and run is excellent and effective. There was high praise both for the facilitation of the meeting and the superb work of the support staff. Also, all agreed that using laptop computers, pre-loaded with Peer Review Criteria Forms for each project, was a great improvement that should certainly be continued. One Reviewer noted that at a similar type of meeting he had attended, the organizers attempted to network the computers, which was a total disaster. The system employed at this meeting worked perfectly.

The individual project presentations and 20-minute question-and-answer period that followed were held in open session. Although there was general agreement that open sessions are valuable, it was suggested that in cases where it was important to the Panel to elicit information from an original equipment manufacturer (OEM), the Q&A should be conducted in closed session (i.e., limited to just the Presenter, the ASME Review Panel, and DOE/NETL staff).

Other general process suggestions included loading the individual project presentation onto the reviewers' laptop computers, but to continue also providing hard copy, as that was very useful for note-taking, and to put a Peer Review Criteria Form behind the hard copy of each presentation into the binders for the Reviewers, so it could be used for note-taking during a presentation.

Meeting Agenda

Several Reviewers said they appreciated the presentations given by the NETL Technology Managers at the start of each session. These presentations helped to give "context" to the project presentations that followed.

Another comment was to give more thought to the order of presentations to ensure a logical flow, especially where projects fit together.

Presentations

In general, the presentations received high marks; however, several suggestions were made for future Peer Review Panel presentations:

- Do not use half-page graphs; they are too hard to read.
- Provide an introduction in early slides to help bring a diverse panel "up to speed." Show baseline information, flow diagrams, and how the project fits into the NETL program.
- Standardize what is meant by "commercially available."
- Do not repeat the program goals in every presentation; this is repetitious and wastes time.

Pre-Meeting Documentation and Pre-Review Panel Questions

One Reviewer commented that he would have benefited from seeing a DOE Fossil Energy/NETL organization chart that showed the programs, projects, and relevant organizations, and showed who is sponsoring what, and why.

Review Panel

Reviewers were unanimous in commenting on how stimulating and rewarding it was to work with such a highly qualified technical panel and how the panel had brought out the best in the presenters.

Two specific comments were made regarding the make-up of the Panel:

1. That it was good to include generalists to look at the overall programs as well as experts in specific fields to look at technical aspects of individual projects.
2. Including operations people added a key perspective to the discussions.

APPENDICES

APPENDIX A - ASME Peer Review Methodology

Background

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 ASME's technical depth within its membership and its long commitment to supporting research programs, the Society has often been asked to provide independent, unbiased, and timely review of technically related research by others, including the Federal government. After long years of experience, the Society has developed a standardized approach to reviewing research projects. The purpose of this section is to give a brief overview of the review procedure established for the U.S. Department of Energy (DOE)/National Energy Technology Laboratory (NETL) 2007 Advanced Power Systems (APS) Peer Review.

ASME Knowledge and Community (K&C) Sector

One of the five sectors responsible for the activities of ASME's 125,000 members worldwide, the K&C Sector is charged with the dissemination of technical information, providing forums for discussions to advance the profession, and managing the Society's research activities.

Center for Research and Technology Development (CRTD)

The mission of the 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 Center is governed by the Board on Research and Technology Development (BRTD). The BRTD has organized over a dozen research committees in specific technical areas. Day-to-day operations of the CRTD are handled by a 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 Review Panel; provides facilitation of the actual review meeting; and prepares all summary documentation.

Board on Research and Technology Development (BRTD)

The BRTD governs the activities of the CRTD. 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 BRTD and to function as liaisons between BRTD and the appropriate ASME Sectors, Boards, and Divisions.

Advanced Power Systems 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 to see that all ASME rules and procedures are followed, to review and approve the qualifications of those asked to sit on the Review Panel, to insure that there are no conflicts of interest in the review process, and to review all documentation coming out of the project review. There must be at least three members of the Peer Review Executive Committee. They must have experience relevant to the program being reviewed. Members of the APS 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.** Sargent and Lundy. Mr. Stenzel is a former chair of the ASME Power Division and past member of the ASME Energy Committee.
- **William Worek.** University of Illinois. Dr. Worek is a past Vice-President of the Energy Resources Group and former chair of the Solar Energy Division. He currently serves on the ASME Mechanical Engineering Department Heads Committee.

Advanced Power Systems Peer Review Panel

The APS Peer Review Executive Committee accepted resumes for proposed 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 alternatives, the ASME Peer Review Executive Committee oversaw the selection of a 10-member APS Peer Review Panel and agreed that they had the experience necessary to review the broad range of projects under this program. The Review Panel in this case was large because of the need to cover multiple disciplines, including policy analysis, chemical engineering, combustion, novel concepts, systems analysis, power/utility economics, IGCC process design, air separation, turbine design, and metallurgy.

Meeting Preparation and Logistics

Prior to the meeting, the project team for each project to be reviewed was asked to submit an 11-page "Project Summary Sheet" summarizing the goals of their project, accomplishments to date, etc. A standard set of specifications for preparing this document was provided by CRTD. These Project Summary Sheets were collected and sent to the Peer Review Panel for background reading prior to the meeting. Based on their review of these project summaries, the Reviewers were encouraged to provide questions or issues that needed clarification. These were forwarded to the PIs to assist them in preparing for the Peer Review Meeting.

Also, ahead of the review meeting, a complete set of instructions was provided to all project teams on the standard format to be used in delivering a summary of their project to the Review Panel. All presentations were done in PowerPoint format with hard-copy handouts of these slides provided to the Reviewers.

Project Presentations, Evaluations, and Discussion

At the APS Peer Review meeting, presenters were held to a time limit (typically 30 minutes but sometimes longer for large or multi-lab projects) so that all projects could be presented equitably within the limits of a four-day review meeting. After each presentation, the project team interacted with the Review Panel for 20 minutes of questions and answers.

Following each presentation, the Review Panel spent 20 minutes considering the material that had been presented. To start, each Reviewer scored the project against a set of predetermined Peer Review Criteria. Ten criteria were used:

- Scientific and Technical Merit
- Anticipated Benefits if Successful
- Technical Approach
- Rate of Progress
- Knowledge of Related Research
- Economic Analysis
- Utilization of Government Resources
- Commercialization Potential
- Consideration of Possible Adverse Effects
- Attention to Constituent's Concerns

For each of these Review Criteria, individual Reviewers "scored" each project as to whether it is:

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

After determining their individual evaluations, the Review Panel members each provided written comments about the project. At this Peer Review Meeting, for the first time, Reviewers were provided with laptop computers (or brought their own if they chose to) that were pre-loaded with Peer Review Criteria Forms for each project to facilitate this process. Finally, the Review Panel discussed the project for the purpose of defining: project strengths, project weaknesses, recommendations for other possible activities by the project team, and a list of action items that the team should address as a result of the review.

APPENDIX B - Meeting Agenda

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

Advanced Power Systems Peer Review
Hyatt Regency Pittsburgh International Airport
July 16 - 19, 2007

AGENDA

Monday Program, July 16, 2007

8:00 - 9:00 a.m. Continental Breakfast - Open to all

- Closed Session -
Open to Department of Energy and American Society of Mechanical Engineers Personnel Only

9:00 - 10:30 a.m. **APS Peer Review Panel Kick Off Meeting**
- Review of ASME Peer Review Process - Michael Tinkleman/Kim Hart, ASME
- Meeting Logistics/Completion of Forms - Steven Ostheim/Charles Schmidt, TMS
- Role of NETL - José Figueroa, NETL

Overview of IGCC and Advanced Research Portion of Advanced Power Systems
- Gary Stiegel, Gasification Technology Mangager, NETL
- Robert Romanosky, Advanced Research/Combustion Technology Manager, NETL

10:30 - 10:45 a.m.	**Break**
10:45 - 11:30 a.m.	***Project # 40343*** - ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems, *Phillip Armstrong*, **Air Products & Chemicals, Inc.**
11:30 - 11:50 a.m.	Q&A
11:50 - 12:15 p.m.	Discussion, evaluation, and written comments
12:15 - 1:15 p.m.	**Lunch (on your own)**
1:15 - 1:45 p.m.	***Project # 40675*** - Novel Technologies for Gaseous Contaminants Control, *Raghubir Gupta,* **Research Triangle Institute**
1:45 - 2:05 p.m.	Q&A
2:05 - 2:25 p.m.	Discussion, evaluation, and written comments
2:25 - 2:30 p.m.	Set-up/Transition allowance between presentations
2:30 - 3:00 a.m.	***Project # 41866*** - Hybrid Combustion-Gasification Chemical Looping Coal Power Technology Development, *Herbert Andrus*, **Alstom Power, Inc.**
3:00 - 3:20 p.m.	Q&A
3:20 - 3:40 p.m.	Discussion, evaluation, and written comments
3:40 - 3:55 p.m.	**Break**
3:55 - 4:55 p.m.	***Project # 25140*** - Power Systems Development Facility, *Kerry Bowers*, **Southern Company Services, Inc.**
4:55 - 5:15 p.m.	Q&A
5:15 - 5:45 p.m.	Discussion, evaluation, and written comments

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TUESDAY PROGRAM, JULY 17, 2007

7:00 - 8:00 a.m.	Continental Breakfast - Open to all
8:00 - 8:30 a.m.	***Project # 42469*** - Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants, *Doug Jack*, **Eltron Research, Inc**.
8:30 - 8:50 a.m.	Q&A
8:50 - 9:10 a.m.	Discussion, evaluation, and written comments
9:10 - 9:25 a.m.	**Break**
9:25 - 9:55 a.m.	***Project # ORD-07-22068-1*** - Refractory Materials for Slagging Gasifiers, *Cynthia Powell*, **National Energy Technology Laboratory**
9:55 - 10:15 a.m.	Q&A
10:15 - 10:35 a.m.	Discussion, evaluation, and written comments
10:35 - 10:40 a.m.	Set-up/Transition allowance between presentations
10:40 - 11:10 a.m.	***Project # T401.01.04*** - 2006 Cost and Performance Baseline for Fossil Energy Plants, *Julianne Klara*, **National Energy Technology Laboratory**
11:10 -11:30 a.m.	Q&A
11:30 - 11:50 a.m.	Discussion, evaluation, and written comments
11:50 - 12:50 p.m.	**Lunch (on your own)**
12:50 - 1:20 p.m.	***Project # 41922*** - New Optical Sensor Suite for Ultra High Temperature Fossil Fuel Applications, *Russell May*, **Prime Research, LLC**
1:20 - 1:40 p.m.	Q&A
1:40 - 2:00 p.m.	Discussion, evaluation, and written comments
2:00 - 2:05 p.m.	Set-up/Transition allowance between presentations
2:05 - 2:35 p.m.	***Project # 41175*** - Development of Advanced Materials for Ultrasupercritical Boiler Systems, *Vis Viswanathan and Robert Purgert*, **Energy Industries of Ohio**
2:35 - 2:55 p.m.	Q&A
2:55 - 3:15 p.m.	Discussion, evaluation, and written comments
3:15 - 3:30 p.m.	**Break**
3:30 - 4:15 p.m.	***Project # FEAA028*** - Fossil Energy Advanced Research Materials Program, *Roddie Judkins*, **Oak Ridge National Laboratory**
4:15 - 4:35 p.m.	Q&A
4:35 - 5:05 p.m.	Discussion, evaluation, and written comments
7:00 - 8:00 p.m.	Final Comments on IGCC/Advanced Research Projects by Reviewers

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Wednesday Program, July 18, 2007

7:00 - 8:00 a.m.	Continental Breakfast - Open to all

- Closed Session -
Open to Department of Energy and
American Society of Mechanical Engineers Personnel Only

8:00 - 8:30 a.m.	**Overview of Advanced Turbines Portion of Advanced Power Systems** - Richard Dennis, Turbines Technology Manager, NETL

8:30 - 9:15 a.m.	***Project # 41431*** - University Turbine Systems Research (UTSR) Program, *Robert Leitner*, **South Carolina Institute for Energy Studies**
9:15 - 9:35 a.m.	Q&A
9:35 - 10:00 a.m.	Discussion, evaluation, and written comments
10:00 - 10:05 a.m.	Set-up/Transition allowance between presentations
10:05 - 10:35 a.m.	***Project # 42643*** - Advanced IGCC/Hydrogen Gas Turbine Development, *Kevin Collins*, **GE Energy, Inc.**
10:35 - 10:55 a.m.	Q&A
10:55 - 11:15 a.m.	Discussion, evaluation, and written comments
11:15 - 11:30 a.m.	**Break**
11:30 -12:00 p.m.	***Project # 42644*** - Advanced Hydrogen Turbine for FutureGen, *Joseph Fadok*, **Siemens Power Generation**
12:00 - 12:20 p.m.	Q&A
12:20 - 12:40 p.m.	Discussion, evaluation, and written comments
12:40 - 1:40 p.m.	**Lunch (on your own)**
1:40 - 2:10 p.m.	***Project # 42650*** - Novel Concepts for the Compression of Carbon Dioxide, *Klaus Brun*, **Southwest Research Institute**
2:10 - 2:30 p.m.	Q&A
2:30 - 2:50 p.m.	Discussion, evaluation, and written comments
2:50 - 2:55 p.m.	Set-up/Transition allowance between presentations
2:55 - 3:25 p.m.	***Project # 42651*** - CO_2 Compression Using Super Sonic Shock Wave Technology, *Pete Baldwin*, **Ramgen Power Systems**
2:25 - 3:45 p.m.	Q&A
3:45 - 4:05 p.m.	Discussion, evaluation, and written comments
4:05 - 4:15 p.m.	**Break**

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WEDNESDAY PROGRAM, JULY 18, 2007 - CONTINUED

4:15 - 4:45 p.m.	***Project # ORD-07-220623-2*** - Combustion Systems for Hydrogen-Based Turbines, *Kent Casleton and Pete Strakey*, **National Energy Technology Laboratory**
4:45 - 5:05 p.m.	Q&A
5:05 - 5:25 p.m.	Discussion, evaluation, and written comments

THURSDAY, JULY 19, 2007

7:00 - 8:00 a.m.	Continental Breakfast
8:00 - 8:30 a.m.	***Project # 42646*** - Zero Emissions Coal Syngas-Oxygen Turbo Machinery, *Mohan Hebbar and Jim Downs*, **Siemens Power Generation**
8:30 - 8:50 a.m.	Q&A
8:50 - 9:10 a.m.	Discussion, evaluation, and written comments
9:10 - 9:15 a.m.	Set-up/Transition allowance between presentations
9:15 - 9:45 a.m.	***Project # 42645*** - Coal-Based Oxy-Fuel System Evaluation and Combustor Development, *Scott MacAdam*, **Clean Energy Systems**
9:45 - 10:05 a.m.	Q&A
10:05 - 10:25 a.m.	Discussion, evaluation, and written comments
10:25 - 10:40 a.m.	**Break**
10:40 - 11:10 a.m.	***Project # 42652*** - Systems Analysis of Advanced Brayton Cycles, *Scott Samuelsen*, **University of California at Irvine**
11:10 -11:30 a.m.	Q&A
11:30 - 11:50 a.m.	Discussion, evaluation, and written comments
11:50 - 12:45 p.m.	**Lunch (on your own)**
12:45 - 1:15 p.m.	***Project # FWP-FEAA070*** - Materials Issues in Coal-Derived Synthesis Gas/Hydrogen Fired Turbines, *Ian Gordon Wright*, **Oak Ridge National Laboratory**
1:15 - 1:35 p.m.	Q&A
1:35 - 1:55 p.m.	Discussion, evaluation, and written comments
1:55 - 2:00 p.m.	Set-up/Transition allowance between presentations
2:00 - 2:30 p.m.	***Project # T401.01.06*** - Development of Baseline Performance Values for Turbines in Existing IGCC Applications, *Walter Shelton*, **National Energy Technology Laboratory**
2:30 - 2:50 p.m.	Q&A
2:50 - 3:10 p.m.	Discussion, evaluation, and written comments
3:10 - 3:40 p.m.	**Review Break**
3:40 - 5:00 p.m.	Final Comments on Turbine Projects by Reviewers and Overall Meeting Wrap-up

APPENDIX C - Peer Review Panel Members

Background

After reviewing the wide range of scientific and engineering related issues represented by the 21 projects to be reviewed, the CRTD staff and the ASME Peer Review Executive Committee in cooperation with NETL developed the following list of "Areas of Expertise" that would need to be represented by the 2007 Advanced Power Systems (APS) Peer Review Panel:

Areas of Expertise:

- Policy Analyst
- Chemical Engineering
- Combustion
- Novel Concepts (including membranes and coatings)
- Systems Analysis
- Power/Utility Economics
- IGCC Process Design
- Air Separation
- Turbine Design
- Metallurgy

It was also important that the Peer Review Panel represent the distinctly different perspectives of the academia, industry, government, and non-profit sectors.

Considering the "Areas of Expertise" listed above, the CRTD carefully reviewed the resumes of all those who had previously served on Carbon Sequestration Peer Review Panels, acknowledging the benefit of their previous experience in this form of Peer Review Meeting, and a number of new submissions both from DOE and those resulting from a limited call to ASME members with relevant experience. It was determined that four of those who had served on the Carbon Sequestration Review Panel were well qualified to serve on the APS Review Panel.

Appropriate resumes were then submitted to the APS Peer Review Executive Committee for review. Ten members were selected for the 2007 APS Peer Review Panel:

- Dr. John F. Clarke, Department of Homeland Security
- Dr. William H. Day, Consultant
- Mr. Daniel J. Kubek, Consultant
- Mr. Bruce Reynolds, Idaho National Laboratory
- Mr. M. Brett Shelton, Dominion Energy
- Mr. James C. Sorensen, Consultant
- Dr. David Thomas, Consultant
- Mr. Douglas M. Todd, Consultant
- Mr. Paul M. White, Dominion Energy
- Dr. Raymond L. Zahradnik, Consultant

A brief summary of their qualifications follows. In addition to reviewing materials from the principal investigators sent prior to the meeting, each Review Panel member spent four days together at the review session in Pittsburgh. Evaluation and review comments were collected at that time. Panelists received an honorarium for their time as well as reimbursement of travel expenses.

2007 Advanced Power Systems Peer Review Panel Members

John F. Clarke, Sc.D

Dr. Clarke is currently serving as Deputy Director of the Office of National Laboratories in the Science and Technology Directorate of the Department of Homeland Security (DHS) under an Intergovernmental Personnel Agreement. Before his DHS assignment, he was responsible for the macro-economic characterization and analysis of energy and environmental technologies within Joint Global Change Research Institute integrated assessment models and the Global Technology Strategy Project. In the latter capacity, Dr. Clarke managed the nuclear, bio-technology, and fusion energy strategic technology analysis projects. The focus of his research work is in the application of conditional choice theory to the market competition of energy technologies in macro-economic models. At the US Department of Energy (DOE), Dr. Clarke served as Executive Director of DOE Climate Activities and was DOE representative to the Intergovernmental Panel on Climate Change (IPCC). Prior to his government service, Dr. Clarke was the Director of the Fusion Energy Division at Oak Ridge National Laboratory. He received a Bachelor's Degree in physics and philosophy at Fordham University, and earned a Master of Science degree in plasma physics and a Doctor of Science degree in nuclear engineering at the Massachusetts Institute of Technology.

William H. Day Ph.D

Dr. Day is a consultant, most recently for four years at the South Carolina Institute for Energy Studies (SCIES) whose work includes Integrated Gasification Combined Cycle (IGCC) efforts for the US Department of Energy (DOE). Prior to this, he spent 23 years at United Technologies (UTC) where he was a Pratt & Whitney Fellow and Manager of Advanced Industrial Programs. Before joining UTC, Dr. Day was Manager of Advanced Program Management and Product Planning for General Electric (GE). In his 19 years at GE, Dr. Day's work included successfully proposing and then running the first Electric Power Research Institute (EPRI) and DOE industrial gas turbine development program; winning a 4-way competition for a $32 million DOE High Temperature Turbine Technology Program and then managing the program; and managing development of IGCC systems. In 1995, Dr. Day founded the Gas Turbine Association in Washington, DC that successfully lobbied Congress to retain the Advanced Turbine Systems Program and to establish the Next Generation Gas Turbine Program. He received a Bachelor of Science degree in Mechanical Engineering from Cornell University, and earned a Master of Science degree and his doctorate from the Polytechnic Institute of Brooklyn.

Daniel J. Kubek

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 H_2S removal and CO_2 capture and sequestration. Prior to this, Mr. Kubek was with UOP for 18 years as Senior Technology Manager. His primary work was for UOP's Solvent Absorption, Molecular Sieve Adsorption, and H_2 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

Bachelor of Science degree in Chemical Engineering from Rutgers University and earned a Master of Science in Chemical Engineering from Purdue University.

Bruce Reynolds

Mr. Reynolds is currently Department Manager, Fossil Energy Technology for Idaho National Laboratory (INL). The Fossil Energy Technology Department has responsibility for all aspects of oil and natural gas exploration and production, crude refining and utilization technologies, development of compressed natural gas fueling stations, natural gas liquefaction technologies, alternate fueled vehicles, synthetic liquid fuel production, coal, hydrogen, carbon dioxide sequestration, and methane hydrates. Mr. Reynolds has management responsibility for INL's participation in the Big Sky Regional CO_2 Sequestration project. He a technical advisor to the Center for Advanced Engineering Studies and the Center for Space Nuclear Fuel at INL, and on the board of directors for The Energy Systems Technology and Education Center (ESTEC) at Idaho State University. Prior to joining INL, Mr. Reynolds was a Program Manager for six years with Battelle Pacific Northwest National Laboratory (PNNL). At PNNL, he was point of contact for the "Refinery of the Future" Initiative in the Strategic Alliance with the Mexican Petroleum Institute (IMP) and the National Autonomous University of Mexico (UNAM). Mr. Reynolds received a Bachelor of Science degree in Chemical Engineering with Honors from the University of Nebraska and earned a Master of Science in Chemical Engineering from Massachusetts Institute of Technology.

M. Brett Shelton

Mr. Shelton is a consulting engineer with Dominion Energy responsible for all aspects of materials engineering for the fossil and hydro business unit, both regulated and merchant. He has over 25 years of engineering experience in failure analysis and prevention, fracture mechanics and fatigue, component condition assessment, selection of materials for component design, corrosion control, and application of codes and standards relating to power plant operation and maintenance with emphasis on inspection, defect assessment, and repair. Mr. Shelton developed and organized the operation of a corporate failure analysis laboratory for the investigation of power plant component failures; conducted failure analyses of hundreds of diverse fossil, nuclear, and hydroelectric power generation equipment failures; and provided written recommendations for avoiding repeat failures and extending component life that significantly improved plant reliability. And he developed and implemented a risk-based condition assessment program with demonstrated cost savings of over $1,000,000 in the first year. Mr. Shelton received a Bachelor of Science degree in Materials Engineering from Virginia Tech and earned a Master of Science of Materials Science from the University of Virginia. He is also a registered Professional Engineer (Virginia).

James C. Sorensen

Mr. Sorensen is a consultant specializing in the conception and development of clean coal and other energy programs with a focus on Integrated Gasification Combined Cycle (IGCC), Oxy-Fuel Combustion, Gas-To-Liquids (GTL), and Air Separation and Hydrogen/syngas technology. Prior to this, he worked for Air Products and Chemicals both as Director, New Markets and as Director, Gasification and Energy Conversion. While in these positions, his achievements included developing and selling a $26 million Ultra Clean Fuels technology development program that was selected by the US Department of Energy (DOE), selling a $30 million single train separation facility for a 250 mw IGCC power plant, proposing and developing a $22.5 million fossil fuel R&D program selected by DOE, and leading Air Products effort on a multi-team proposal selected by DOE for a $180 million Clean Coal Technology award. Mr. Sorensen is the founding chairman of the Gasification Technologies Council. He received a Bachelor of Science degree in Chemical Engineering from the California Institute of Technology and earned a Master of Science in Chemical Engineering from Washington State University. Mr. Sorensen also earned a Master of Business Administration in General Management from Harvard Business School.

David C. Thomas, Ph.D
Dr. Thomas is currently a Senior Technical Advisor with Advanced Resources International providing consulting services to industry and government on CO_2 mitigation technology and policy related issues. He is also a consultant to the CO_2 Capture Project (CCP), a multi-national, multi-company CO_2 mitigation research program, where he has organized and managed the CCP's communications with the US Department of Energy (DOE) and is the Chief Editor of CCP's technology results volumes published in January 2005 by Elsevier Science. Prior to this, Dr. Thomas worked for BP Amoco Corporation for 24 years including as Manager, CO_2 Mitigation Technology, Green Operations. In this position, he led an international team responsible for a CO_2 mitigation program worldwide, led development of a group-wide technology strategy for Green Operations technology and implementation through a balanced program of technology sharing through step-change technologies, and had oversight and budgetary responsibility for CO_2 mitigation technology including the CO_2 Capture Project – a major joint industry project bringing together nine international energy companies and three governments to address greenhouse gas reduction. Dr. Thomas received a Bachelor of Science degree in Chemistry from Baker University and earned a Master of Science in Inorganic Chemistry from The University of Akron. He also earned a doctorate in Physical Chemistry from The University of Oklahoma.

Douglas M. Todd
Mr. Todd is the owner and President of Process Power Plants LLC, a consulting company dedicated to integrating Gas Turbine Combined Cycles with Gasification systems (IGCC) to provide extremely clean, economical electric power and other useful products from low cost fuels. Mr. Todd's experience includes 35 years with GE Company in engineering, marketing, and product management positions culminating with business management responsibility for GE's Process Power Plants Organization. He was responsible for developing and introducing Combined Cycle and IGCC Power Plant technology on a worldwide basis including setting up an in-country Gas Turbine Manufacturing Agreement with China. Gas turbine technology development combined with technology partnerships led to worldwide acceptance of IGCC with 22 IGCC plants announced, totaling 6000 mw. Mr. Todd was involved directly with 16 IGCC projects with eight different gasification technologies. He received the first European IChemE Medal for Excellence in Gasification in 2002 and the Gasification Technologies Council Lifetime Achievement Award in 2003. Mr. Todd received a Bachelor of Science degree in Chemical Engineering from Worcester Polytechnic Institute.

Paul M. White
Mr. White is a Manager at Dominion Energy responsible for providing gas turbine technical support for 71 gas turbines– ranging from 1960 to current advanced technology – located on 20 sites. He also manages a group of technical support personnel spanning operations, controls, and maintenance expertise. Mr. White's group is responsible for technical and commercial negotiations for $0.5 billion major maintenance services contracted across the Dominion fleet. Previously, he was with Duke Power for 19 years including Director of Engineering for Duke Energy North America, where he was responsible for strategic turbine expertise in both current and developing technologies, and Senior Engineer, Gas Turbine Technical Support for Duke Power—Power Generation. Mr. White is involved with many combustion turbine group organizations including as the current Steering Committee Co-Chairman, GE 7F User Group – the largest gas turbine fleet user organization worldwide – and the US Department of Energy Advanced Turbine Systems (ATS) Program. He received a Bachelor of Science degree in Mechanical Engineering for NC State University and he is also a registered Professional Engineer (North Carolina and South Carolina).

Raymond L. Zahradnik, Ph.D

Dr. Zahradnik is a consultant and partner in Appalachian-Pacific LLC. He is currently carrying out a $4.6 million project awarded to Appalachian-Pacific by the US Department of Energy (DOE) to produce LNG from coal mine methane as an alternative transportation fuel. Prior to working as a private consultant, he worked for Occidental Petroleum Corporation for 14 years first as Director of Energy Research, then as President of Occidental Oil Shale, Inc. In the latter capacity, Dr. Zahradnik oversaw all of Occidental's oil shale activities including a large field-test facility and a commercial venture involving a leasehold property from the US Department of the Interior (DOI). He also worked for various branches of the Federal Government including the National Science Foundation and DOI mostly involved in energy subjects. And Dr. Zahradnik was acting head of the Office of Coal Research and Director of the Coal Conversion and Utilization Department at the Energy Research and Development Administration (ERDA). Previous to this, he was Professor of Chemical Engineering at Carnegie-Mellon University for six years. Dr. Zahradnik earned his Bachelor of Science degree in Chemical Engineering, Master of Science in Chemical Engineering, and doctorate in the same field from Carnegie-Mellon University.

APPENDIX D - Peer Review Criteria Form

PEER REVIEW PANEL MEMBERS
U. S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
2007 ADVANCED POWER SYSTEMS
PEER REVIEW MEETING
JULY 16 TO 19, 2007

Project Title:	
Principal Investigator:	
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) **Project Merit;** (2) **Approach and Progress**: 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.

PEER REVIEW RATING CRITERIA

Please evaluate the project against each of the 10 criterion listed below. Definitions for these 10 criterion 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**				
(Criteria Definitions, refer to Page 4)		(Rating Criteria Definitions, refer to Page 1)				
		Results Not Demonstrated*	Ineffective	Adequate	Moderately Effective	Effective
PROJECT MERIT						
1	Scientific and Technical Merit					
2	Anticipated Benefits if Successful					
APPROACH AND PROGRESS						
3	Technical Approach					
4	Rate of Progress					
5	Knowledge of Related Research					
6	Economic Analysis					
7	Utilization of Government Resources					
DEPLOYMENT CONSIDERATIONS						
8	Commercialization Potential					
9	Possible Adverse Effects Considered					
10	Attention to Constituent's Concerns					
***Please explain why the project was rated "Results Not Demonstrated" for a particular criterion**						

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 Item(s):
General Comments:

CRITERION DEFINITIONS

PROJECT MERIT:

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: Anticipated Benefits if Successful

- A clear statement of potential benefits if research is successful.
- Technologies being developed can benefit other programs.
- Significant contribution towards meeting near- and long-term program cost and performance goals.

APPROACH AND PROGRESS:

3: Technical Approach

- Work plan is sound and supports stated goals.
- A thorough understanding of likely technical challenges.
- Effective methods to address likely technical uncertainties.

4: Rate of Progress

- Progress to date against stated goals and schedule is reasonable.
- Continued progress against possible barriers is likely.
- Overall momentum is sufficient to achieve goals and benefits.

5: Knowledge of Related Research

- Familiar with relevant literature in the field.
- Up to date with reference citations.
- In communication with other experts in this field and no duplication.

6: Economic Analysis

- At least "ballpark" estimates made of costs to implement.
- Cost estimates are sensible given uncertainties.
- There is hope of meeting ultimate DOE cost and performance goals.

7: Overall Utilization of Government Resources

- Research team is adequate to address project goals.
- Good rationale for teaming or collaborative efforts.
- Equipment, materials, and facilities are adequate to meet goals.

DEPLOYMENT CONSIDERATIONS:

8: Commercialization Potential

- Researchers know and can describe a “real world” application.
- Basic metrics of this application have been at least theorized.
- An adequate market exists and the technology being developed is likely to be implemented if research is successful.
- Barriers to commercialization have been identified and addressed.

9: Possible Adverse Effects Considered

- Potential negative effects on the environment or public have been considered.
- Scientific risks are within reasonable limits.
- Mitigation strategies have been considered.

10: Attention to Constituent Groups Concerns

- Relevant constituent groups have been identified.
- An assessment of positive or negative reactions has been made.
- A plan for constituent relations has been considered.

APPENDIX E - APS Project Summaries

Presentation ID Number	Project Number	Title
01	FT40343	ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems
02	FT40675	Novel Technologies for Gaseous Contaminants Control
03	NT41866	Hybrid Combustion-Gasification Chemical Looping Coal Power Technology Development
04	MC25140	Power Systems Development Facility (PSDF)
05	NT42469	Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants
06	ORD-07-22068-1	Refractory Materials For Slagging Gasifiers
07	T401.01.04	2006 Cost and Performance Baseline for Fossil Energy Plants
08	NT41922	New Optical Sensor Suite for Ultra High Temperature Fossil Fuel Applications
09	NT41175	Development of Advanced Materials for Ultrasupercritical Boiler Systems
10	FEAA028	Fossil Energy Advanced Research Materials Program
11	NT41431	University Turbine Systems Research (UTSR) Program
12	NT42643	Advanced IGCC/Hydrogen Gas Turbine Development
13	NT42644	Advanced Hydrogen Turbine for FutureGen
14	NT42650	Novel Concepts for the Compression of Carbon Dioxide
15	NT42651	CO_2 Compression Using Super Sonic Shock Wave Technology
16	ORD-07-220623-2	Combustion Systems for Hydrogen-Based Turbines
17	NT42646	Zero Emissions Coal Syngas-Oxygen Turbo Machinery
18	NT42645	Coal-Based Oxy-Fuel System Evaluation and Combustor Development.
19	NT42652	Systems Analysis of Advanced Brayton Cycles
20	FWP FEAA070	Materials Issues in Coal-Derived Synthesis Gas/Hydrogen-Fired Turbines
21	T401.01.06	Development of Baseline Performance Values for Turbines in Existing IGCC Applications

01: FT40343

Project Number: DE-FC26-98FT40343	**Project Title:** Development of ITM Oxygen Technology for Integration in IGCC and Other Advanced Power Generation Systems (Abbreviated Title: ITM Oxygen)		
Contacts DOE/NETL Project Mgr.	**Name** Arun Bose	**Organization** DOE/NETL	**E-Mail** arun.bose@netl.doe.gov
Principal Investigator	Phillip A. Armstrong Air Products and Chemicals, Inc. armstrpa@airproducts.com		
Partners	Ceramatec, Inc., GE Energy Gasification Division, Concepts/NREC, Eltron Research, NovelEdge Technologies, LLC, SOFCo EFS (formerly McDermott Technology, Inc.), Pennsylvania State University, University of Pennsylvania, Siemens Power Generation, Inc.		
Stage of Development	__Basic R&D X Applied R&D X Proof of Concept __Demonstration		

Technical Background:

Modern cryogenic distillation for oxygen production is mature technology. Indeed, air separation plants are now some of the most efficient distillation-based separations known. 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 step-change reduction in the cost of producing oxygen. Two alternative air separation technologies, adsorption and polymeric membrane separations, are limited in use: the efficiency limitations inherent in the former restricts its application to relatively small plants (<150 tons per day (TPD) oxygen production), while the latter does not provide the separation factor and flux required for economical large-scale oxygen production.

Recognizing the potential of 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. These ion transport membrane (ITM) materials separate oxygen from air at high temperature in an electrochemically driven process. The oxygen in air is ionized on the surface of the ceramic and diffuses through the membrane as oxygen ions, forming oxygen molecules on the other side. Impurities such as nitrogen are rejected by the membrane. Because these materials conduct electrons as well as ions, no external source of electrical power is required. 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 capital and operating costs of oxygen production are predicted. This potential for efficiently co-producing oxygen and power at reduced cost fits the goals of DOE's Advanced Power Systems Program.

Relationship to NETL Advanced Power Systems Program:

By integrating the energy-rich, non-permeate stream with a gas turbine system, the overall process co-produces high-purity oxygen, power and steam if desired. As a result, the technology is ideally suited for advanced energy conversion processes such as IGCC or decarbonized fuel cycles that require oxygen and use heavy carbonaceous feedstocks (resid oils, bitumens, coke, renewables, coal), as well as for traditional industrial applications for oxygen and distributed power.

Primary Project Goal:

This project aims to develop a new air separation technology—Ion Transport Membrane (ITM) Oxygen—based on ceramic membranes that selectively transport oxygen ions when operated at high temperature. The aim of this new technology is to reduce the cost of oxygen by one third.

Objectives:

Phase	***Broad Objectives***
I	Demonstrate basic feasibility of technical approach and re-confirm expected commercial economics
II	Demonstrate scale-up to commercial-scale membrane components sufficient to Provide engineering basis for full-scale design
III	Demonstrate technology at a sufficient scale (i.e., 100-150 TPD) to provide the Necessary engineering basis for designing a 500 to 2000 TPD oxygen plant for FutureGen.

The development effort has focused on identifying key technical and commercial objectives required for commercialization and addressing them comprehensively with a multi-disciplinary, multi-organizational team approach. Air Products and DOE have garnered broad industrial and academic perspective and participation. Key performing partners include or have included Ceramatec, Inc., for ceramic processing expertise; the GE Energy Gasification division (formerly a part of Texaco) for process economic modeling and applications knowledge; Concepts/NREC for combustion expertise; Eltron Research for materials development; McDermott Technology, Inc., (now SOFCo EFS) for mechanical and vessel systems development; Pennsylvania State University for materials characterization; the University of Pennsylvania for oxide materials science; Siemens Power Generation, Inc. (SPGI) for identification of detailed requirements for integrating its gas turbine machinery with ITM Oxygen systems; and NovelEdge Technologies, LLC for steam system integration studies. In addition, the team continues to attract interest from a variety of potential industrial partners who recognize the value of the technology and wish to share in its benefits.

02: FT40675

Project Number: DE-AC26-99FT	**Project Title:** Novel Technologies for Gaseous Contaminant Control
Contacts DOE/NETL Project Mgr.	**Name** **Organization** **E-Mail** Suresh Jain DOE/NETL suresh.jain@netl.doe.gov
Principal Investigator/ Project Mgr.	Raghubir Gupta RTI International gupta@rti.org
Partners	Partners Eastman Chemical Company Membrane DuPont Air Liquide (MEDAL) University of Texas North Carolina State University Prototech Company SRI International Kellogg, Brown, and Root ChevronTexaco Süd Chemie, Inc. URS Corporation Mustang Engineering
Stage of Development	__Basic R&D X Applied R&D X Proof of Concept __Demonstration

Gasification is the cleanest and most thermally efficient way to convert the energy content of coal and other carbonaceous feedstocks into more useful products such as electricity, hydrogen, clean fuels, and value-added chemicals. The product of gasification – synthesis gas (commonly called "syngas") – is a mixture of hydrogen (H_2) and carbon monoxide (CO) and represents the building block from which all of these valuable products are generated. Developing reliable and cost-effective gasification technologies can ensure that the U.S. energy requirements will be met using coal as an abundant, low-cost, and domestic resource.

One major roadblock in market penetration of gasification technologies is that the use of coal and other carbonaceous feedstocks in a gasifier produces several gaseous contaminants, including hydrogen sulfide (H_2S), carbonyl sulfide (COS), ammonia (NH_3), hydrogen cyanide (HCN), hydrogen chloride (HCl), arsine (AsH_3), mercury (Hg) and alkali vapors. If allowed to remain in the syngas, these contaminants can damage downstream process equipment as well as cause serious harm to the environment. To remove these contaminants, highly efficient and cost-effective technologies are needed to retain the high cycle thermal efficiency inherent to gasification. To this end, Research Triangle Institute (RTI) and its partners are developing sorbent-based processes that remove the above contaminants from coal-derived syngas. They also are being designed to remove these contaminants at moderate temperatures (i.e., 450 to 700°F).

One of the main components of this project is the High Temperature Desulfurization System (HTDS). HTDS is a sorbent-based technology that may eventually replace amine systems as the primary method for H_2S and COS removal (desulfurization) from syngas. This system has the major advantage of removing sulfur species at temperatures of 450 to 700ºF, unlike existing amine systems where required cooling of the syngas results in large economic and thermal penalties.

The key to maximizing the advantages of HTDS is to have a sorbent that is both regenerable and mechanically robust enough to withstand the system's harsh operating conditions. As part of the current project, RTI has developed and commercialized a specialized, zinc oxide- (ZnO) based breakthrough desulfurization sorbent (named "T-2749,") that meets these criteria. In 2004, R&D Magazine recognized "T-2749" with an R&D 100 Award.

In addition to sulfur removal technologies, this project is also aimed at developing processes to remove the other contaminants found in coal-derived syngas, including a sorbent-based process that removes NH_3 at temperatures of 400 to 500ºF; disposable sorbents designed for fixed-bed operation and used to treat HCl, arsine, and Hg vapors at 400 to 600ºF; and membrane systems for separation of H_2S and CO_2 from the syngas stream.

Relationship to NETL Advanced Power Systems Program:

This project seeks to develop the enabling technology for future coal-based that can be used to generate electric power, hydrogen, transportation fuels and chemicals with near-zero emissions with significantly reduced capital and operating costs and higher thermal efficiencies. As such this project supports gas cleaning and conditioning technologies in the gasification systems technology portfolio of DOE/NETL's Advanced Power Systems Program.

Primary Project Goal:

The overall goal of this project is to demonstrate syngas cleaning technologies that are thermally efficient and cost effective for treating H_2S, COS, NH_3, Hg, and arsine, in pilot plant testing with real coal-derived syngas.

Objectives:

The specific objectives are to:

- Demonstrate the removal of sulfur species (H_2S and COS) to < 60 part per billion volume (ppbv) levels using a combination of sorbent and membrane technologies
- Demonstrate NH_3 removal technologies (process and sorbent) that achieve less than 10 parts per million volume (ppmv) of the contaminant in the treated syngas
- Demonstrate removal to <10 ppbv levels for HCl, AsH_3, and Hg vapor using inexpensive disposable materials
- Achieve capital cost reductions of $60-80/kWe and cycle efficiency improvements of >1 efficiency points for warm syngas cleaning technologies

03: NT41866

Project Number: DE-FC26-03NT41866	**Project Title:** Hybrid Combustion-Gasification Chemical Looping Coal Power Technology Development		
Contacts DOE/NETL Project Mgr.	**Name** Suresh C. Jain	**Organization** U.S. DOE	**E-Mail** jain@netl.doe.gov
Principal Investigator	Herbert E. Andrus, Jr. herbert.e.andrus@power.alstom.com	ALSTOM POWER	
Partners	John H. Chiu Peter T. Stromberg Paul R. Thibeault Dr. John R. Grace Dr. Frederic A. Zenz	ALSTOM POWER ALSTOM POWER ALSTOM POWER University of British Columbia PEMM Corp.	john.h.chiu@power.alstom.com peter.t.stromberg@power.alstom.com paul.r.thibeault@power.alstom.com jgrace@chml.ubc.ca fazenz@verizon.net
Stage of Development	__Basic R&D __ Applied R&D	X Proof of Concept	__Demonstration

Technical Background:

ALSTOM has over 100 years of experience in successfully developing and commercializing advanced combustion and gasification processes for the world-wide coal-fired power generation market. Over 40% of the world's electric utility boilers are of ALSTOM design. This background provides a firm basis for ALSTOM's Chemical Looping process. In particular, three of ALSTOM's earlier technical developments provide the technical and commercial basis for ALSTOM's Chemical Looping process:

- ALSTOM's Air-blown, Entrained-flow, Slagging Coal Gasification process,
- ALSTOM's Circulating Fluidized Bed (CFB) boiler technology
- ALSTOM's Hot Solids Coal Gasification process.

ALSTOM's Chemical Looping process uses air, carbon-based fuel, limestone and steam to produce hydrogen and capture CO_2. Heat and product gas produced by the process can be directly used to produce electricity via Rankine cycle, Brayton/Rankin cycle, fuel cell cycles, etc. ALSTOM's process can also produce hydrogen, syngas (CO/H_2) and transportation fuels (via Fischer-Tropsch, etc.) using any carbon-based fuel (e.g. all types of coal, biomass, petcoke, etc.). Over 95% of the carbon in the fuel is captured as a nearly pure CO_2 stream (for use or sequestration).

This concept has the following advantages:

- avoids the large investment costs and parasitic power associated with either cryogenic air separation units (ASU's) or oxygen transport membranes;
- captures CO_2 at temperatures higher than the power cycle temperatures, thus eliminating the thermodynamic penalty normally associated with CO_2 capture;
- fast chemical reactions allow for small equipment and low capital cost;
- conventional material of construction and fabrication techniques; and well defined costs.

Because of these factors, ALSTOM's chemical looping concept provides the lowest cost method of capturing CO_2 found to-date.

ALSTOM's process (Figure 1) consists of the oxidation, reduction, carbonation, and calcination of limestone-based compounds, which chemically react with coal, biomass, or opportunity fuels.

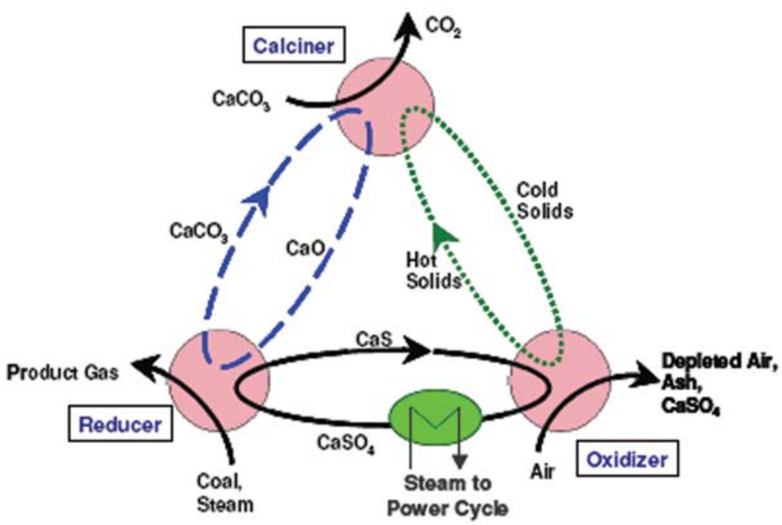

FIGURE 1 – CHEMICAL LOOPING GASIFICATION WITH HYDROGEN PRODUCTION AND CO_2 CAPTURE

Limestone makeup calcines to produce CaO (Calciner). CaO captures the sulfur in the fuel to produce CaS (Reducer). CaS is burned to produce hot $CaSO_4$ (Oxidizer). Hot $CaSO_4$ gasifies coal (Reducer) and produces syngas (CO and H_2) and CaS for reuse. Steam shifts CO to H_2 and CO_2 (Reducer). CaO Captures CO_2 (Reducer) forming $CaCO_3$ and producing hydrogen product gas. $CaCO_3$ is calcined (Calciner) using hot solids from Oxidizer producing near-pure CO_2 for use or sequestration and CaO for reuse. Coal ash and sulfur (as $CaSO_4$) are purged. Product gas (H_2 or syngas) and steam are used for power, etc.

Relationship to NETL Advanced Power Systems Program:

This program will develop a hybrid combustion/gasification chemical looping system usable with any carbon-based fuel (e.g. any coal, biomass, petcoke, etc.) that will supply a stream of CO_2 for use or sequestration and will produce high temperature steam and/or H_2 or syngas for clean, high efficient power or for industrial purposes. This will be part of US DOE NETL's technology base for a highly efficient near-zero-emissions power plant of the future.

Primary Project Goal:

Develop an entirely new, ultra-clean, low cost, high efficiency power plant for the global power market with the following Objectives:

- Over 90% CO_2 capture from coal;
- Less than $20/ ton, avoided cost of CO_2 capture;
- Capital cost – 20% lower than Conventional Boiler Island (without CO_2 liquification);
- Beat Steam Power and IGCC performance and economics, world-wide; and
- Medium-Btu gas or Hydrogen without an Oxygen Plant.

Objectives:

Phase 0: Design and construct a small-scale process development unit (PDU).

Phase 1: Complete testing on the PDU, to determine coal/$CaSO_4$ gasification/combustion rates, CaS/$CaSO_4$ looping feasibility and solids transport feasibility for design of a 3 MWt prototype of the process shown in Figure 1.

Phase 2: Complete the development of the CaO/$CaCO_3$ carbonate looping, CO_2 capture and hydrogen production in the PDU for design of a prototype of the process.

Phase 3: Obtain remaining necessary solids transport, scale-up and automatic controls information to design a viable prototype of the commercial Chemical Looping concept.

Phase 4: Design, build and operate a prototype (5 to 10 million BTU's per hour of coal) to provide the basis for a 50 to 100 MWe Demonstration Plant at an existing electric plant.

Phase 5: Design, build and operate a demonstration plant to demonstrate the reliability and performance of ALSTOM's chemical looping process.

04: MC25140

Project Number: DE-FC21-90M25140	**Project Title:** Power Systems Development Facility (PSDF)		
Contacts DOE/NETL Project Mgr.	**Name** Elaine Everitt	**Organization** Gasification & Fuels Division	**E-Mail** elaine.everitt@netl.doe.gov
Principal Investigator	Kerry Bowers Southern Company Services (SCS) – PSDF kwbowers@southernco.com		
Partners	Nicola Salazar KBR (formerly Kellogg, Brown and Root) Nicola.Salazar@kbr.com Other cost sharing participants include: Siemens Power Generation; BNSF (Burlington Northern Santa Fe); Electric Power Research Institute Peabody Energy; Lignite Energy Council		
Stage of Development	__Basic R&D __ Applied R&D X Proof of Concept __Demonstration		

Technical Background:

The strategic objective of DOE's Advanced Power Systems program is to create public-private partnerships to provide technology to ensure continued economic production of electricity from the extensive U.S. fossil fuel resource, including control technologies to permit reasonable-cost compliance with emerging regulations. The Gasification Program Goals coincide with these strategic objectives. Gasification system improvements are needed to overcome barriers to gasification system acceptance (economics, efficiency, feedstock flexibility and system reliability). The PSDF located in Wilsonville, Alabama, was established to strengthen the U.S. effort to develop cost-competitive, environmentally acceptable, coal-based power plant technologies. The PSDF includes an engineering scale demonstration of key components of an Integrated Gasification Combined Cycle (IGCC) power plant, including a KBR Transport Gasifier, a Siemens hot gas filter using candle-type filter elements, syngas cooling, and high pressure solids handling systems. These components are designed at sufficient size to provide data for commercial scale-up. The KBR Transport Gasifier is a circulating fluidized bed reactor operating at higher circulation rates and riser densities than conventional circulating bed units – resulting in higher throughput, better mixing, and higher mass and heat transfer rates. Since the gasifier uses a dry feed system, it is well-suited for high moisture fuels such as subbituminous and lignite coals, but can also process some higher-rank coals. Virtually all the particulate from the syngas exiting the gasifier is removed by the downstream filter. System commissioning and initial test campaigns were performed in combustion mode from 1996 to 1999. Gasification operation began in late 1999, with four gasification commissioning tests completed by early 2001, and there have been 17 test campaigns since. As of May 2007, the PSDF gasification process had been operated for more than 10,000 hours. Filter element materials must be compatible with gasification operating conditions and be able to withstand system upsets. Many different types of elements have been tested at the PSDF, including monolithic ceramic, ceramic composite, sintered metal powder, and sintered metal fiber. The ceramic elements were primarily used in early combustion-mode tests at temperatures around 1400ºF. The filter operating temperature was reduced to around 750ºF for gasification, making it possible to use the more durable metal elements. In addition to semi-commercial scale testing, the PSDF has slip-stream testing capability for cost effective technology screening. Future PSDF work will include (1) scale-up and continued development of several CO_2 capture technologies being developed either at DOE's NETL facility, at private R&D laboratories or at PSDF as well as; (2) support for FutureGen; (3) efforts to enhance the coal feeding systems to enable wider ranges of coal as well as biomass to be economically and reliably introduced into many different versions of IGCC technology under consideration commercially today; and (4) synergistic use of DOE & PSDF capabilities in technology modeling screening, and engineering/economic assessments.

Relationship to NETL Advanced Power Systems Program:

The PSDF is an element within the Advanced Gasification Program, one of four program areas making up DOE's Gasification Technologies R&D program. While one focus for PSDF is related to DOE's program purpose of developing a portfolio of innovative technology, such as the Transport Gasifier, much of the work conducted, currently and in the future, also supports the other three program areas—Gas Cleaning & Conditioning; Gas Separation; and Systems and Industry Analyses.

Primary Project Goal:

The PSDF was established by the US-DOE to strengthen the nation's effort in developing environmentally-acceptable, cost-effective, reliable coal-based power generation technologies.

Objectives:

PSDF conducts integrated system and component testing at sufficient size to provide data for commercial scale-up. Testing accelerates the development of major technologies identified by DOE as essential to maintaining coal as a provider of cost-competitive power.

05: NT42469

Project Number: DE-FC26-05NT42469	**Project Title:** Scale-up of Hydrogen Transport Membranes for IGCC and FutureGen Plants		
Contacts DOE/NETL Project Mgr.	**Name** Arun Bose	**Organization** DOE-NETL	**E-Mail** arun.bose@netl.doe.gov
Principal Investigator	Doug S. Jack Eltron Research & Development doug.s.jack@eltronresearch.com Michael Mundschau Eltron Research & Development mmundschau@eltronresearch.com		
Partners	Praxair, Inc. troy_raybold@praxair.com NORAM Engineering & Constructors Ltd. cbrereton@noram-eng.com CoorsTek rnkleiner@earthlink.net		
Stage of Development	__Basic R&D __ Applied R&D X Proof of Concept __Demonstration		

Technical Background:

This technology is based on use of a dense metallic composite membrane system for the separation of hydrogen and carbon dioxide from a coal-based synthesis gas stream, although it does have wider applicability to other hydrogen-containing streams. Earlier programs evaluated ceramic materials, ceramic-metallic composites (cermets) and metallic alloy membranes. Based on that work, the metallic alloy based systems were chosen for further work. These are composite membranes that have been shown to meet the 2010 targets for flux, selectivity and cost (see attached table). The membrane has been operated at 1000 psig and differential pressure up to 500 psig on simulated synthesis gas compositions. Membrane life has been shown for about 8000 hours. Some early work on impurity testing has shown tolerance to sulfur up to 20 ppm. The membrane has also been integrated into a WGS reactor, facilitating high conversion of CO. Process design and economics studies have shown cost and thermal efficiency benefits. The program is now shifting from proof of concept to demonstration. Two patents have been issued with another application pending.

Relationship to NETL Advanced Power Systems Program:

This program is being funded through the hydrogen from coal effort and in support of FutureGen. It also addresses effective capture of CO_2; the system enables capture of CO_2 at essentially gasifier pressure.

Primary Project Goal:

Develop a high throughput, low cost H_2 separation system suitable for application with coal-based synthesis gas, including improved tolerance for contaminants (S, Hg, etc) and enabling cost effective capture of CO_2 for sequestration.

Objectives:

Program objectives are grouped into 5 major areas

Materials Development: Develop and test membrane alloy systems that give the best flux without risk of membrane embrittlement; Develop catalyst compositions that do not limit flux and provide the requisite tolerance to impurities; Understand the importance of the interface between the membrane and catalyst.

Performance Screening: Establish the range of operating conditions for the system giving the best performance using WGS composition syngas; Evaluate the effect of impurities on performance.

Process Design: Integrate the system into IGCC flow sheets, testing different configurations – with and without co-production of power and H_2; Evaluate impact of different impurity management techniques; Compare economics, including capex & opex, versus alternative technologies.

Mechanical Design: Address manufacturing issues for scaling up of system taking into account maintenance costs, initial capital costs and system robustness; Evaluate tubular versus planar configurations for scale-up of system; Address issues such as welding, sealing, catalyst deposition techniques and alloy manufacture.

System Scale-up: Currently at 1.5 lbs/day H_2 production; Design build and operate 220 b/day system on coal-based syngas slipstream, developing operating procedures and gathering initial engineering data for further scale-up; Design, build and operate 4 TPD unit to complete engineering package for commercial design and demonstrate large-scale manufacturing capabilities. (Commercial module expected to be ~25-40 TPD scale)

06: ORD-07-22068-1

Project Number: ORD-07-220681	**Project Title:** Refractories Materials for Slagging Gasifiers		
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Stage of Development	__Basic R&D X Applied R&D X Proof of Concept X Demonstration		

Technical Background:

Service life of the refractory liners in slagging gasifiers is one of the key limitations to targeted reliabilities and on-line availabilities of gasification facilities. In addition, there is a growing push to take advantage of the technology's capability for fuel flexibility (particularly biomass), which leads to concerns regarding the applicability of chromium containing gasifier liner materials in such systems and their potential for the formation of hexavalent chrome. Current commercial refractories installed in air cooled slagging gasifiers fail in as little as three months of service in high wear areas, and last no longer than two years in the least demanding locations. As a result, the gasifier industry has identified refractory service life as a key barrier to wide spread commercialization of gasification technology. Failure of the refractory lining is expensive, both in terms of material replacement costs (as high as $1,000,000) and in lost production (due to gasifier shut down). Users desire a gasifier availability of 85-95% for utility applications and more than 95% in applications such as chemical feedstock production. To meet these availability goals and reduce operation costs, gasifier operators would like to install refractory linings with a reliable life of at least three years. Failure to meet these criteria creates a potential roadblock to widespread acceptance and commercialization of advanced gasification technologies. Research in NETL's Office of Research and Development has aimed at fundamentally understanding refractory failures in gasifiers, and has utilized that knowledge to design and patent a new, high-performance chrome oxide refractory. Field trials of the NETL-developed refractory in commercial slagging gasifiers have indicated that service life can be extended by up to 50 percent, compared to other commercially-available materials. Current research is focusing on non-chrome refractory compositions that will combine greater reliability with fuel flexibility.

Another critical gasifier component that has a relatively short service life is the thermocouple used to monitor and control gasification temperature. Thermocouples typically fail within 100 days, and replacement requires depressurization of the gasifier and process shutdown. Thus, longer thermocouple life is also needed to enhance the reliability of gasification technology.

Relationship to NETL Advanced Power Systems Program:

Gasification is a critical technology to the success of the DOE's Near Zero Emissions Advanced Fossil Fuel Power Plants, and could play a key role in defining the long-term energy security with regard to both power and liquid fuels. As a result, one goal of the Advanced Power Systems program is to enhance the performance of gasification systems, enabling US industry to improve the competitiveness of gasification processes. This research project, which seeks to eliminate a key barrier to acceptable on-line availability of slagging gasifier systems through the development of improved high-performance refractory materials, contributes directly to the meeting of this goal.

Primary Project Goal:

The goal of this project is the development of high-performance refractory materials that can improve the on-line availability and economics of slagging gasifiers and provide the opportunity for seamless fuel flexibility.

Objectives:

Broad project objectives center on developing cost effective refractories and temperature monitoring devices with improved service life for use in slagging gasifiers. NETL ORD is investigating two types of refractory materials: (1) chromium oxide-based and (2) chromium free (no chromium oxide). Chromium free refractories are viewed as a potential alternative to high chromium oxide refractories, and are targeted towards future gasifier feedstocks high in alkali or alkaline earths that may form hexavalent chromium oxide (a regulated hazardous waste) as a result of reaction with chrome-bearing refractories.

Improved refractory materials development will be accomplished by: 1) fundamentally understanding the primary causes of failure through post-mortem analysis of gasifier refractories and thermocouples; 2) engineering materials with enhanced resistance to the identified failure modes, followed by production and performance evaluation at laboratory scale; 3) scaling up of promising materials for further evaluation in the laboratory under simulated gasifier conditions; 4) field testing promising material compositions in commercial systems; and 5) refining compositions and transferring technology to the refractories and gasification industries. The research will be accomplished in stages; first by improving currently used high chromium oxide refractories to meet performance goals, than applying information learned to non-chromium oxide materials; and finally by improving thermocouple performance. The high temperature materials developed must limit slag attack and penetration from multiple feedstock sources, such as coal, petroleum coke, or combinations of them. Successful refractory materials must also have resistance to thermal cycling, load bearing capability at elevated temperatures, and be thermodynamically stable in the hot gases present in a gasifier.

07:T401.01.04

Project Number: T401.01.04	**Project Title:** 2006 Cost and Performance Baseline for Fossil Energy Plants		
Contacts DOE/NETL Project Mgr.	**Name** Julianne M. Klara	**Organization** NETL/OSAP	**E-Mail** julianne.klara@netl.doe.gov
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Partners			
Stage of Development	__ Basic R&D __ Applied R&D __ Proof of Concept __ Demonstration X System Analysis		

Technical Background:

The goal of Fossil Energy RD&D is to ensure the availability of ultra-clean ("zero" emissions), abundant, low-cost, domestic electricity and energy (including hydrogen) to fuel economic prosperity and strengthen energy security. A broad portfolio of technologies is being developed within the Clean Coal Program to accomplish this objective. Ever increasing technological enhancements are in various stages of the research "pipeline," and multiple paths are being pursued to create a portfolio of promising technologies for development, demonstration, and eventual deployment. The technological progress of recent years has created a remarkable new opportunity for coal. Advances in technology are making it possible to generate power from fossil fuels with great improvements in the efficiency of energy use while at the same time significantly reducing the impact on the environment, including the long-term impact of fossil energy use on the Earth's climate. The objective of the Clean Coal RD&D Program is to build on these advances and bring these building blocks together into a new, revolutionary concept for future coal-based power and energy production.

The objective of this analysis is to establish baseline performance and cost estimates for today's fossil energy plants with a focus on bituminous coal. To do this, it is necessary to understand the current state of technology. Such a baseline can be used to benchmark the progress of the Fossil Energy RD&D portfolio. This study establishes the baseline cost and performance for Pulverized Coal Combustion (PC), Integrated Gasification Combined Cycles (IGCC), and Natural Gas Combined Cycles (NGCC), all with and without carbon dioxide capture and storage assuming that the plants use technology available today. The results, which were developed using a consistent basis, will serve as a baseline for future NETL studies. Further, it is expected to be a landmark report for public consumption filling a gap in current cost and performance estimates for fossil energy plants.

Relationship to NETL Advanced Power Systems Program:

This analysis is relevant to several advanced power systems technologies including gasification, turbines, and sequestration.

Primary Project Goal:

To establish a baseline for the performance and cost of today's fossil energy plants to be used to benchmark the progress of the Advanced Power Systems R&D portfolio

Objectives:

1. Establish a design basis and consistent set of assumptions for PC, IGCC and NGCC power plants both with and without carbon capture and sequestration.
2. Complete mass and energy balances using ASPEN software and estimate capital and O&M costs for each case using EPC expertise.
3. Perform financial analysis to estimate levelized COE for each case.
4. Peer review draft report.
5. Update analysis based on peer review comments.
6. Produce final report.
7. Produce summary presentation.
8. Produce desk reference.

08: NT41922

Project Number: DE-FC26-03NT41922	**Project Title:** New Optical Sensor Suite for Ultra High Temperature Fossil Fuel Applications		
Contacts DOE/NETL Project Mgr.	**Name** Susan Maley	**Organization** Gasification & Fuels Projects Div.	**E-Mail** Susan.Maley@netl.doe.gov
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Stage of Development	__ Basic R&D	X Applied R&D	__ Proof of Concept __ Demonstration

Technical Background:

Development of optimized high-temperature clad optical fiber based on single-crystal sapphire fibers will enable the application of advanced photonic sensor techniques, including optical interferometry, to high-temperature instrumentation. Currently, sapphire fibers with high temperature cladding are not available; the cladding is essential for improvement of the waveguiding properties of the fiber in order to employ advanced optical techniques. Practical high-temperature cladding materials must have the appropriate refractive index, spectral attenuation, coefficient of thermal expansion, melting point, and must be chemically and thermodynamically compatible with the sapphire fiber. Development of practical clad sapphire fibers for high temperature instrumentation is a goal of this project. In addition, the development of techniques to modify the local refractive index of the sapphire fiber core in specific locations, through chemical doping or through irradiation by ultraviolet laser, will permit new optical sensor methods to be implemented with sapphire fibers. Development of doped or writable sapphire fibers is another key goal of the program.

This project seeks to extend photonic sensor technology by developing optical fibers and structures based on single-crystal sapphire, to enable measurements of strain and temperature. Also, new sensor interrogation methods will be developed to permit distributed strain and temperature measurements to be obtained along an optical fiber, for use in investigating temperature distribution and strains in solid oxide fuel cell components.

Relationship to NETL Advanced Power Systems Program:

This project is a fundamentally based effort to develop sensor for harsh environments which is a key focus of the Sensor and Control technology area of the Advanced Power System Program.

Primary Project Goal:

The goal of this project is the research and development of advanced, robust photonic sensors based on improved sapphire optical waveguides, and the identification and demonstration of applications of new photonic sensors in advanced fossil fuel power plants, where the new technology will contribute to technology will enable development and characterization of materials for the fuel cells.

Objectives:

The key research objectives involve: (1) The development of new processing methods to produce the ultrahigh temperature clad and writable sapphire fiber; (2) the demonstration of the novel cladding and doping technique for sapphire to design and fabricate optical sensors; and (3) demonstration of new, ultrahigh temperature optical sensors for specific measurements that have been deemed most valuable for integration into the control systems of advanced power systems. Accomplishments of these objectives will allow the Recipient and its team members to develop a stable and reproducible product/process design of photonic based sensors that can be easily integrated into the designs of future power generation facilities.

09: NT41175

Project Number: 41175	**Project Title:** Development of Advanced Materials for Ultrasupercritcal Coal Boiler Systems		
Contacts	**Name**	**Organization**	**E-Mail**
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Partners	ALSTOM Power, Babcock & Wilcox, Foster Wheeler Development Corp, Riley Power, Oak Ridge National Laboratory (participation funded separately by DOE – FEAA061)		
Stage of Development	__ Basic R&D X Applied R&D __ Proof of Concept __ Demonstration		

Technical Background:

In the 21st Century, the world faces the critical challenge of providing abundant, affordable electricity to meet the needs of a growing global population, while at the same time, limiting environmental impact. Most studies of this issue conclude that a robust portfolio of generation technologies and fuels should be developed to assure that the United States (US) will have adequate electricity supplies in a variety of possible future scenarios. Coal is the US's most plentiful natural energy resource, but traditional methods of power production from coal emit pollutants (including CO_2) at high levels relative to other generation options. Maintaining coal as a generation option will require methods for addressing these environmental issues. One of the pathways for achieving the goal of utilizing the available large quantities of indigenous coal, at the same time reducing emissions, is by increasing the efficiency of power plants by utilizing much higher steam conditions known as UltraSuperCritical (USC). One of the challenges in this path is the availability of materials that can withstand the demanding operating conditions. This project, through a government/industry consortium, has just completed a five-year effort (Phase I) to evaluate and develop materials technologies that allow the use of advanced USC steam cycles in coal-based power plants. These advanced cycles, with target steam temperatures up to 1400°F (760°C), will increase the efficiency of coal-fired power plants and reduce emissions substantially. In addition to a reduction in heat rejection, fuel consumption, and all fuel-related emissions, there are additional benefits to higher efficiency that favorably impact carbon management. Studies have shown that such boilers could be designed to allow start-up with air, but operate with oxygen and recirculated flue gas blend (to replace the nitrogen). This so-called oxy-fuel combustion option produces a concentrated stream of carbon dioxide which greatly improves the economics of capture. This oxy-fuel option also requires little additional equipment, and may actually eliminate some of the currently-required air quality control equipment, depending on the purity requirements for carbon capture and sequestration. The USC technology is thus completely compatible with the goals of achieving near-zero emissions in future energy systems. This project is now beginning a second phase of work investigating oxy-combustion materials issues as well as extending key studies from the first phase.

Relationship to NETL Advanced Power Systems Program:

The Advanced Power Systems Program seeks to develop cost-effective, high-efficient technological capability to dramatically reduce air pollution from coal-fueled electricity generation plants. This project will accomplish that through the development of materials that can be used for coal-fired boilers operating at ultrasupercritical conditions thereby increasing efficiency to 45 to 47% while reducing CO_2 and other fuel-related emissions by as much as 30%.

Primary Project Goal:

Identify and evaluate advanced materials that help achieve highly efficient, cost competitive, and environmentally acceptable pulverized coal combustion based electric power generation that can lead to energy sufficiency in the US at near-zero emission levels through the use of USC steam conditions.

Objectives:

1. Determine the pressure part material requirements for a USC boiler, defining the limitations of conventional materials and the appropriate range of test conditions for developmental materials. Investigate the economics of USC plant capital and operating costs and determine the feasibility of such plants.
2. Identify candidate alloys and determine key mechanical properties through testing of samples.
3. Investigate steamside oxidation behavior of candidate alloys and protective coatings.
4. Investigate fireside corrosion behavior of candidate alloys and protective coatings.
5. Develop practical welding procedures for such alloys.
6. Confirm practical fabricability and establish any limitations for such alloys.
7. Investigate external and internal coating materials and methods for protection against oxidation and corrosion.
8. Evaluate ASME Code stress analysis methods, weld strength issues, and contribute to ASME Code approval efforts for new materials.

10: FEAA028

Project Number: FEAA028	***Project Title:*** Fossil Energy Advanced Research Materials Program		
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Stage of Development	__ Basic R&D X Applied R&D __ Proof of Concept __ Demonstration		

Technical Background:

The DOE-FE Advanced Research Materials Program is the only DOE-Fossil Energy (FE) program directed specifically to materials development. The Program includes R&D at national laboratories, universities, and industrial research centers. The charter of the Program is to conduct crosscutting long-range, high-risk, and high-payoff R&D to address the needs of advanced power systems being pursued by DOE-FE. The principal development areas are organized into ensembles or clusters of projects with the projects complementing one another to contribute to success of the particular cluster of projects. In turn, the research clusters are directed to addressing the overall goals and objectives of the Program. Particular projects and certainly all the research clusters extend/crosscut the various advanced power systems being pursued by DOE-FE and NETL.

The NETL-ORNL partnership was formally established through a Memorandum of Agreement (MOA) between NETL, the DOE Oak Ridge Office, and ORNL, and the MOA recognizes ORNL's premier status in materials R&D among the national laboratories and, indeed, in the world. The contract vehicle between DOE and ORNL for this particular program is ORNL Field Work Proposal (FWP) No. FEAA028, which is updated and amended annually. This FWP provides details on R&D being conducted at ORNL on this program. Supporting subcontracts are issued by ORNL to universities and industrial R&D units. ORNL provides technical direction and guidance to the other national laboratories, and those laboratories submit their FWPs to ORNL and NETL for concurrence with the proposed work.

As noted above, the character of the Program is crosscutting, meaning simply that projects more often than not are applicable to more than one advanced power generation technology. Long-range R&D in the context of this Program means that the projects often extend from the state of discovery or invention, through the characterization and evaluation stage, into and through fabrication development, to transfer of the technology to elements of the DOEFE/NETL Advanced Power Systems Program and/or directly to industry.

The R&D clusters include New Alloy Development, Coatings and Protection of Alloys, Breakthrough Concepts, and Functional Materials. All of the activities are structured to ensure that all of the critical enabling technologies are supporting development needed for the Advanced Power Systems Program. Materials have been identified by DOE as a critical supporting technology, which means that without acceptable materials, those enabling technologies, e.g., synthesis-gas-fired turbines, gas separation systems, for advanced power systems will be constrained in their level of performance. The R&D conducted on the program is comprehensive in scope and develops the materials of construction, including processing and fabrication methods, and functional materials necessary for components of advanced power systems. Example cases from the R&D clusters will be the basis for this review.

Relationship to NETL Advanced Power Systems Program:

The scope of the Program addresses materials requirements for all fossil energy systems, including materials for coal fuels technologies and for advanced power generation technologies such as coal gasification, heat engines, combustion systems, and fuel cells. The Program is aligned with the development of those technologies that are potential elements of the DOE-FE and FutureGen concept, which aim to address and solve environmental issues and thus remove them as a constraint to coal's continued status as a strategic resource.

Primary Project Goal:

The goal of the Fossil Energy AR Materials Program is to provide a materials technology base to assure the success of coal fuels and advanced power generation systems being pursued by DOE-FE. The focus is on research leading to a scientific understanding of high-performance materials compatible with hostile fossil environments.

Objectives:

1. Develop/improve the fundamental understanding of the solid-state phase transformations in 9 Cr Steels
2. Confirm the efficacy of and construct/operate a pilot-scale Silicon Carbide Fibrils Synthesis Reactor
3. Develop an effective and efficient air separation material and process based on a magnetoadsorption effect using activated carbon composites
4. Develop alloy modifications, fabrication methods, and joining techniques that will enable the practical application of oxide-dispersion-strengthened ferritic steels
5. Develop alloys and application methods for FeCrAl weld overlay coatings
6. Extend the ORNL inorganic membrane technology to oxygen separation

11: NT41431

Project Number: DE-FC26-02NT41431	**Project Title:** University Turbine Systems Research (UTSR) Program		
Contacts DOE/NETL Project Mgr.	**Name** Tom George Robert Leitner	**Organization** NETL SCIES	**E-Mail** tom.george@netl.doe.gov Rleitne@clemson.edu
Principal Investigator	Robert Leitner	SCIES	Rleitne@clemson.edu
Partners	SCIES manages the UTSR program with the support of three major groups of partners. They are: • Performing Member Universities who conduct all of the research. There are 111 performing member universities. A total of 39 research subcontracts have been awarded from among these universities • Industrial Review Board (IRB) composed of representatives from major gas turbine manufacturers and operators who assist in defining the research topics, reviewing the university proposals, and assessing the progress and relevance of the research efforts. • Academic Advisory Board composed of leading university gas turbine researchers, who assist with defining research efforts and serve in a consultative role.		
Stage of Development	__ Basic R&D X Applied R&D __ Proof of Concept __ Demonstration		

Technical Background:

The DOE Fossil Energy Advanced Power Systems (APS) program is focused on the time phased development of coal based power systems with increased efficiency and emissions performance and decreased capital cost per kW output. These advancements involve a transition from turbines operating on syngas with current IGCC plant properties, to very high hydrogen fuels derived from syngas, to syngas burned in nearly pure oxygen using steam to control temperatures (oxy-fuel systems). This transition requires the development of low emission turbine combustion technologies for this variety of fuels. improved turbine hot section flow path aero/heat transfer methods to accommodate expansion gases that are not only increasingly hotter but also contain higher levels of water vapor and particulates, and durable, low cost materials for this stressing environment.

The UTSR program is focused on obtaining the fundamental technical information needed for gas turbines to support the APS program objectives. The emphasis is on understanding the underlying factors affecting combustion, aero/heat transfer and materials for current IGCC syngas turbines and using that knowledge to design and conduct the research needed to transition to nearly pure hydrogen fuels derived from coal syngas and to syngas burned in oxygen.

Relationship to NETL Advanced Power Systems Program:

The technologies developed within the UTSR program are selected to support APS program efforts in syngas, high hydrogen fuel, and oxy-fuel turbines.

Primary Project Goal:

To develop and transition to the gas turbine industry the technologies necessary to improve combined cycle efficiency by 2-3 percentage points, reduce capital cost by 20-30%, and reduce combustor emissions to 2 ppm NO_X (@ 15% O_2) or less.

Objectives:

Based upon inputs from the IRB, AAB, and NETL, the following objectives were established for the UTSR program in the areas of combustion, aero/heat transfer, and materials:

Combustion

- Generate experimental data for the design of combustors for high hydrogen fuels derived from syngas
- Identify and verify a set of reduced order reactions for syngas/high hydrogen fuels from syngas
- Identify and evaluate operating conditions and design approaches for low emission (NO_X at 2ppm), lean premixed combustors to alleviate or control instabilities while operating with high hydrogen fuel and syngas
- Evaluate factors affecting combustion and emissions performance under conditions of oxy-fuel combustors for a range of H_2, CO, and H_2O compositions representing syngas burned in nearly pure oxygen with low excess oxygen levels and steam for temperature control

Aero/Heat Transfer

- Identify and evaluate hot gas path surface contouring approaches that reduce intensities of secondary flows, heat loads, propensity to collect deposits, and/or decrease aero/heat transfer sensitivity to surface roughness
- Develop innovative cooling approaches or increased film-cooling effectiveness to improve component durability while also decreasing sensitivity to potential surface roughness effects or propensity to collect deposits in and around cooling hole exits
- Define the environments in the hot section of turbines that operate with syngas and high hydrogen fuel

Materials

- Identify the impurities and modes of materials degradation to date in IGCC turbines, explore allowable limits of these impurities to provide insight for syngas impurity specifications for future syngas cleanup systems, and screen and identify the most favorable coatings and alloys for operation in syngas turbines and turbines using higher hydrogen fuels
- Use available information and analyses of degraded TBC's from current syngas turbines along with initial laboratory experiments to determine the critical impurities and degradation mechanisms
- Evaluate methods to alleviate the degradation and represent TBC environments in future turbines operating with higher hydrogen fuels produced from coal syngas
- Evaluate candidate turbomachine alloys and coatings for oxy-fuel systems Specific objectives for each research subcontract are also established.

12: NT42643

Project Number: DE-FC26-05NT42643	***Project Title:*** Advanced IGCC/Hydrogen Turbine Development		
Contacts DOE/NETL Project Mgr.	***Name*** Ron Harp	***Organization*** DOE-NETL	***E-Mail*** rondle.harp@netl.doe.gov
Principal Investigator	Kevin Collins		
Partners	NA		
Stage of Development	__ Basic R&D X Applied R&D __ Proof of Concept __ Demonstration		

Technical Background:

As demand for electricity continues to grow in the United States, there is a clear interest in reducing our dependency on foreign sources of energy. Coal is our most abundant domestic fossil energy resource. In an IGCC (Integrated Gasification Combined Cycle) plant, coal can be converted into a gas (synthesis gas or syngas). This process also lends itself well to carbon capture and storage whereby greenhouse gases such as carbon dioxide and carbon monoxide can be captured and stored rather than released into the environment. The resultant gas (either syngas or "carbon free" syngas – i.e., high hydrogen fuel) can be burned in gas turbines to generate electricity.

In order to more cleanly and more efficiently burn both syngas and high hydrogen fuels, improvements in gas turbine technology are required. This advanced turbine program addresses key technology development needs required to achieve specific DOE performance goals relative to emissions, efficiency, and capital cost. The program is comprised of two phases. Phase I, which began in October 2005 and concludes this September, is focused on conceptual design and technology development. The output of Phase I is a downselection of the key technologies that will be further applied and developed at the component level in Phase II. The four-to-five year Phase II effort will be focused on validating the technologies at a component level. As an example, an advanced combustor will be developed to retrofit to a 7FB IGCC FutureGen-type turbine for possible field testing and validation at the FutureGen site.

The program is comprised of three main technical focus areas (combustion, turbine/aero, and materials) plus a systems level activity. The systems level approach translates the integration of technology improvements into plant performance and investigates the various system trade-offs and their impact on overall plant performance. The combustion element of the program is focused on improving combustion technology to achieve the DOE NO_X emissions target of 2ppm NO_X. Work in this area addresses the challenges of developing a combustion system that can burn both syngas and high hydrogen fuels to produce extremely low NO_X emissions while avoiding flameholding, flashback, and dynamics issues. The turbine/aero element of the program addresses specific turbine technology improvements to address the efficiency targets that have been identified by the DOE (45-50% combined cycle efficiency). The materials portion of the program is focused on applying materials technology to enable the turbine to operate reliably at higher firing temperatures in the IGCC environment. This includes evaluation of advanced alloys and coatings, including targeted use of ceramic matrix composites (CMCs) with environmental barrier coatings (EBCs).

In summary, this comprehensive program addresses the technology development needs for advanced gas turbines for IGCC and FutureGen-type applications while targeting the specific goals identified by the DOE relative to emissions, efficiency, and capital cost.

Relationship to NETL Advanced Power Systems Program:

This program is tied directly to several of the overall DOE Advanced Power Systems' program goals including:

- "By 2010, complete research and development to develop advanced power systems capable of achieving between 45 and 50 percent electrical efficiency at a capital cost of $1000/kW (in constant 2003 dollars) or less for a coal-based plant."
- "By 2010, develop turbine technology that is capable of efficiently utilizing coal derived gases, including hydrogen, for the production of electricity in FutureGen plants."
- "The efficiency of advanced turbine firing synthesis gas must be improved; they must be capable of operating on hydrogen rich gas, without compromising performance; and even lower NO_X emissions must be achieved – less than 2 ppm."

Primary Project Goal:

The primary objective of this program is to develop the technology for a fuel flexible (coal derived hydrogen and syngas) gas turbine that achieves key DOE performance goals relative to efficiency (45-50% combined cycle efficiency), emissions (less than 2ppm NO_X at 15% O_2), and capital cost (less than $1000/kW – 2003$).

Objectives:

Progress is measured on this program through quarterly technical progress reports to the DOE in conjunction with quarterly progress indicators identified to the DOE. Specific milestones to date include:

- Conduct preliminary NO_X entitlement tests and preliminary flame holding tests using current hardware (Complete)
- Prepare IGCC Syngas and Hydrogen fueled Gas Turbine System Performance Models (Complete)
- Prepare specimens for material testing (Complete)
- Test first subscale combustion concept (Complete)
- Preliminary turbine flowpath configuration identified (Complete)
- Complete full-scale DLN single can combustor flame-holding and emissions test and conduct sub-scale testing of alternate first generation pre-mix combustion prototypes (GPRA – Complete)
- Conduct fuel flexibility/operability test on full scale DLN single can combustor (GPRA)
- Down-select to two combustion concepts for further evaluation in Phase II (GPRA)

These milestones provide indicators towards progress being made across the program. Additional milestones will be identified for Phase II of the program later in the year.

13: NT42644

Project Number: DE-FC26-05NT42644	**Project Title:** Advanced Hydrogen Turbine Development for FutureGen		
Contacts DOE/NETL Project Mgr.	**Name** Richard Dennis	**Organization** NETL	**E-Mail** Richard.dennis@netl.doe.gov
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Partners	SC&E, ENEL, ConocoPhilips, Florida Turbine Technology (FTT) University of Central Florida, University of Florida, Georgia Tech, Texas A&M		
Stage of Development	X Basic R&D X Applied R&D __ Proof of Concept __ Demonstration		

Technical Background:

Improving combined cycle efficiency by 3-5% points over the current state of the art contributes directly to the Advanced Power Systems (APS) goal of improving IGCC plant to 45-50% HHV efficiency level. To achieve higher engine and plant efficiencies, thus meeting DOE program goals, gas turbine engine operating conditions must be upgraded and new enhanced technologies developed and implemented. Studies conducted early in the project confirmed the primary drivers of combined cycle efficiency to be gas turbine firing temperature, pressure ratio and turbine exit temperature. The development of technologies required to increase turbine temperature and pressure for a gas turbine fueled with Syngas and Hydrogen while lowering gas turbine emissions is the basis for research and development under this program. The advanced technologies include compressor aerodynamics, low NO_X syngas and hydrogen fuel capable combustion system, novel turbine cooling and aerodynamic design concepts, improved materials and coatings and advanced sensors/diagnostics. These technologies are built upon extensive high temperature experience in G-class engines. In addition to the efficiency improvements, an increase in power island output leads to cost reduction on a $/KW basis.

Relationship to NETL Advanced Power Systems Program:

The Advanced Hydrogen Turbine Development project supports the overall APS goals for a high efficiency (45 – 50% HHV) near zero emissions (2ppmv NO_X @ 15% O_2) and competitive capital cost (<$1000 / KW)

Primary Project Goal:

Develop gas turbine technologies to improve combined cycle (CC) plant efficiency by 3-5 % points above current state of the art systems, reduce CC plant cost by 20-30% and reduce NO_X emissions to meet the 2 ppm APS target.

Objectives:

The objective of this project is to design and develop a fuel flexible (coal derived hydrogen or syngas) gas turbine for IGCC and FutureGen type applications that meets DOE turbine performance goals.

This project will be implemented in two Phases entitled Phase I–Conceptual Design and R&D Implementation Plan: Concept to Commercial Deployment; and Phase II–Design and Validation Test Program. The objectives of these two Phases are:

Phase I–Conceptual Design and R&D Implementation Plan: Concept to Commercial Deployment

- Develop an R&D Implementation Plan that defines in detail the approach, options, cost, risk, schedule and deliverables associated with the R&D required to meet DOE goals and objectives.
- Develop a conceptual design of the turbine that meets program goals. Produce power system level performance models / simulations to show these conceptual turbine designs deployed in likely IGCC and FutureGen type applications will achieve DOE objectives, and conduct the necessary R&D needed to focus or direct Phase II work.
- Conduct necessary materials, combustion, and turbine cooling feature tests to establish feasibility of identified concepts and down select the most promising concepts for further development in Phase II.

Phase II–Basic Design and Validation Test Program

- Develop designs of components and systems required to meet the project objectives, develop validation test plans for technologies, systems and components.
- Perform validation testing of systems and components to demonstrate the ability to attain the Turbine Program performance goal.
- Integrate technologies and subsystems to commercial IGCC applications, FutureGen, and Natural gas fired engines where applicable.

Universities will support testing, validation, and modeling of combustion kinetics, turbine cooling technology development, and advanced alloy materials development.

14: NT42650

Project Number: DE-FC26-05NT42650	**Project Title:** Novel Concepts for the Compression of Carbon Dioxide
Contacts DOE/NETL Project Mgr.	**Name** **Organization** **E-Mail** Tom George DOE/NETL tom.george@netl.doe.gov
Principal Investigator	J. Jeffrey Moore, Ph.D.
Partners	Ms. Marybeth Nored Mr. Ryan Gernentz Dr. Klaus Brun
Stage of Development	__ Basic R&D X Applied R&D __ Proof of Concept __ Demonstration

Technical Background:

One effort being pursued to reduce the release of carbon dioxide (CO_2) greenhouse gas to the atmosphere is sequestration of CO_2 from Integrated Gasification Combined Cycle (IGCC) and Oxy-Fuel power plants. This approach, however, requires significant compression power to boost the pressure to typical pipeline levels. The penalty can be as high as 8% to 12% for a typical IGCC plant.

Relationship to NETL Advanced Power Systems Program:

Reduce carbon capture penalty with IGCC and Oxy-Fuel power.

Primary Project Goal:

For gaseous compression, the project seeks to develop improved methods to compress CO_2 while removing the heat of compression internal to the compressor. The high-pressure ratio compression of CO_2 results in significant heat of compression. Because less energy is required to boost the pressure of a cool gas, both upstream and inter-stage cooling are desirable. This project has determined the optimum compressor configuration and has developed technology for internal heat removal. Other concepts that liquefy the CO_2 and boost pressure through cryogenic pumping have been explored as well.

Objectives:

This project is divided into 3 phases:

- Phase I to develop the most promising concepts that meet the efficiency goals and integrate them into the IGCC environment, has been completed.
- Phase II involves detail design of the optimum solution and prototype development testing.
- Phase III will provide a full-scale compression solution to an existing or proposed IGCC plant.

15: NT42651

Project Number: DE-FC26-06NT42651	**Project Title:** CO_2 Compression Using Supersonic Shock Wave Technology		
Contacts DOE/NETL Project Mgr.	**Name** Tom George	**Organization** DOE/NETL	**E-Mail** tom.george@netl.doe.gov
Principal Investigator	Peter Baldwin	Ramgen Power Systems	pete_Baldwin@ramgen.com
Partners			
Stage of Development	__ Basic R&D	__ Applied R&D	X Proof of Concept X Demonstration

Technical Background:

Ramgen's shock compression technology represents a significant advancement in the state of the art for all compressor applications, and specifically for CO_2 compression. The principal advantage of Ramgen's shock compression is exceptionally high compression efficiency at very high stage compression ratios, enabling lower capital and operating costs.

Ramgen's novel technology addresses the two greatest objectives identified by the Department of Energy for the Capture and Storage of CO_2 – lower costs and better efficiency. Current centrifugal and axial compressor design practice typically limits inlet maximum Mach number to 0.90 to reduce the impact of shock formation within the interblade flow path as both "lossy" and potentially destructive. This practice limits achievable stage pressure ratio to approximately 1.7:1 for CO_2 due to its high molecular weight and lower speed of sound. Consequently, a conventional "high performance" integrally-geared centrifugal compressor processing CO_2 at 100:1 pressure ratio will likely require 8 compression stages and a corresponding number of stainless steel intercoolers between each stage.

Ramgen's rotors, however, create and manage oblique shock structures to generate much higher stage pressure ratio efficiently. The proposed Ramgen CO_2 compressor would achieve 100:1 pressure ratio in two 10:1 stages and employ a single intercooler. Each 10:1 stage would discharge CO_2 at 450-500°F offering significant waste heat recovery without compromising compressor performance. As much as 70% of the electrical input energy could be recovered in the form of useful heat.

Relationship to NETL Advanced Power Systems Program:

Ramgen's CO_2 compressor is uniquely suited to low-cost compression of large volumes of CO_2 produced by carbon separation.

Primary Project Goal:

This program continues the development and demonstration of Ramgen's supersonic compressor technology ultimately resulting in design and construction of a pilot-scale CO_2 compressor for field demonstration.

Objectives:

Phase 1 objectives include:

a) achieve success with ongoing Rampressor-2 testing,

b) define risk areas via Critical Success Factor study,

c) Design Reviews,

d) R&D Implementation Plan,

e) CO_2 compressor conceptual design, and optionally, and

f) Conceptual IGCC plant design.

16: ORD-07-220623-2

Project Number: ORD-07-220623-2	***Project Title:*** Combustion Systems for Hydrogen-Based Turbines	
Contacts	***Name***	***Organization***	***E-Mail***
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	Pete Strakey	US DOE/NETL	peter.strakey@netl.doe.gov
	Doug Straub	US DOE/NETL	douglas.straub@netl.doe.gov
Partners			
Stage of Development	__ Basic R&D X Applied R&D X Proof of Concept __ Demonstration		

Technical Background:

A major driver of the DOE Turbine Program is the need for affordable, clean power-generation options that meet future environmental regulations. Integrated Gasification Combined Cycle (IGCC) coal power plants can utilize domestically abundant coal supplies to generate power, chemical feedstock, or both. If an IGCC plant incorporates carbon-dioxide removal upstream of the gas turbine power island, a significant portion of the carbon in the fuel gas can be removed prior to combustion in the gas turbine. The remaining "carbon-free" syngas entering the turbine combustor is then significantly enriched in hydrogen.

To achieve the DOE Advanced Power Systems (APS) goals, the DOE Turbines Program has established the following performance/cost targets:

- By 2010, operating on syngas: increase combined-cycle (CC) power block efficiency by 2–3 percentage points over baseline; reduce NO_X emissions to 2 ppm in the turbine exhaust at 15 percent oxygen when fueled with syngas; and reduce capital costs of CC power island by 20–30 percent when compared to today's turbines in existing integrated gasification combined-cycle (IGCC) plants.
- By 2012, operating on hydrogen: maintain 2010 efficiency gains (2–3 percentage points for CC power block over baseline) when fueled with hydrogen; reduce NO_X emissions to near-zero when fueled with hydrogen; maintain 2010 capital cost reductions (20–30 percent from baseline) when fueled with hydrogen; and reduce the cost impact of CO_2 compression by reducing the auxiliary power requirement by 30–40 percent compared to current projections.

The demands of improved efficiencies and near-zero emissions performance for coal-derived fuels such as syngas and hydrogen represent a significant challenge for the combustion section of the turbine. This work is directed toward developing turbine combustion technologies that can meet the targets of the DOE Turbines Program in the following general areas:

- Premixed combustors for hydrogen applications,
- Dilute diffusion hydrogen combustion concepts,
- Oxy-fuel combustion, and
- Combustion dynamics.

Relationship to NETL Advanced Power Systems Program:

NETL Advanced Power System Program goals support the development of advanced coal-based power plants with improved efficiency and near-zero emissions. The Turbines Program is a part of the Advanced Power Systems Program, and its key program elements include the development of advanced turbines that operate on coal-derived syngas and hydrogen and the development of oxygen-fired (oxy- fuel) turbines with the goal on near-zero emissions. Work done under the sub-tasks of this effort supports these key Turbines program elements, which in turn support the Advanced Power System Program goals.

Primary Project Goal:

The primary goal for this project is to provide advanced R&D to support the DOE Turbine Program in the development of highly efficient turbine combustors for coal derived fuels such as syngas or hydrogen with near-zero emissions.

Objectives:

This work seeks to provide significant input and support to the long range goal of developing turbine combustors capable of NO_X performance of 2 ppm or less using coal syngas or H_2. In addition, this project supports the development of oxy-fuel combustors capable of near-zero CO_2 emissions. Use of fuels with high H_2 contents in gas turbines raises a number of significant concerns, including flashback, combustion dynamics, flame blowoff, and NO_X formation. This work plan addresses these critical needs through the following objectives:

- identify and evaluate possible combustion alternatives for hydrogen turbine applications
- evaluate/test novel combustor designs, both premixed and non-premixed, for low NO_X operation with high hydrogen fuels.
- investigate methods, both passive and active, to extend the flashback stability limits in high- hydrogen fuels
- measure laminar flame speeds of gas mixtures appropriate for a variety of oxy-fuel combustion applications for gas turbines
- develop and test methods to stabilize combustion in practical applications
- identify the effects of fuel variability on combustion dynamics

17: NT42646

Project Number: DE-FC26-05NT42646	**Project Title:** Zero Emissions Coal Syngas-Oxygen Turbo Machinery	
Contacts DOE/NETL Project Mgr.	**Name** Charles Alsup	**Organization** DOE-NETL	**E-Mail** charles.alsup@netl.doe.gov
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Partners	Scott MacAdam macadam@cleanenergysystems.com	Clean Energy Systems, Inc.	
Stage of Development	X Basic R&D X Applied R&D __ Proof of Concept __ Demonstration (Project requires development of new technologies simultaneous with the application of existing R&D)		

Technical Background:

Advanced power systems that utilize nearly pure oxygen as the oxidant and coal based gaseous fuels are an attractive approach to highly efficient zero emissions coal based systems that capture and sequester carbon dioxide. In these systems, the oxidant and fuel are combusted to create a working fluid composed mostly of steam and CO_2. This working fluid can be utilized in a Rankine cycle turbine to generate power while CO_2 can be captured after condensation of the drive gas mixture. In order to achieve high cycle efficiency, it is necessary to use the drive gas at temperatures comparable to or higher than those of today's gas turbines. Turbines using such a drive gas at high temperatures (1750 deg C or higher) have not been developed.

Power generation using the oxy-fuel combustion process has been demonstrated by Clean Energy Systems (CES), Inc of Rancho Cordova, CA, albeit on a mini scale. The possibility of high efficiency coal-based power generation using utility size turbines, concurrent with no NO_X emissions and almost 100% capture of CO_2 are the drivers behind this technology development.

Relationship to NETL Advanced Power Systems Program:

This program comes under the technology area "Turbines Program".

Primary Project Goal:

Develop high efficiency, advanced turbine technology for utilizing oxy-fuel based working fluid culminating in commercially ready machines in 2015 time frame.

Objectives:

This program involves a partnership with Clean Energy Systems (CES), Inc who was granted a complementary award to develop the oxy-fuel combustor that would supply the working fluid for Siemens turbines. CES is also responsible for plant cycle modeling and optimizing the fluid conditions to maximize the efficiency under baseline, near term and far term scenarios of hardware development. The turbine development program by Siemens is planned in 2 phases.

18: NT42645

Project Number: DE-FC26-05NT42645	***Project Title:*** Coal-Based Oxy-Fuel System Evaluation and Combustor Development		
Contacts DOE/NETL Project Mgr.	***Name*** Charles Alsup	***Organization*** DOE-NETL	***E-Mail*** charles.alsup@netl.doe.gov
Principal Investigator	Scott MacAdam macadam@cleanenergysystems.com	Clean Energy Systems, Inc.	
Partners	Mohan Hebbar mohan.hebbar@siemens.com	Siemens Power Generation, Inc.	
Stage of Development	__ Basic R&D X Applied R&D	__ Proof of Concept	__ Demonstration

Technical Background:

Clean Energy Systems (CES) has a developed a novel oxy-fuel power generation concept that uses proven aerospace technology to enable near zero-emission power generation from fossil fuels. The core of the technology is a high-pressure oxy-combustor that burns gaseous fuels with oxygen in the presence of water to produce a steam/CO_2 working fluid for steam turbines or modified gas turbines. The CES oxy-combustor has been demonstrated mainly on natural gas at CES's 20 MW Kimberlina Power Plant (KPP) outside Bakersfield, CA, where it was used to produce electricity for export to the grid.

Under this DOE award, CES is developing the oxy-combustion technology for coal-based power plants that utilize synthesis gas as the fuel. It is closely associated with DOE award DE-FC26-05NT42646 to Siemens Power Generation to develop high-temperature turbines that would be powered by steam/CO_2 working fluid from the oxy-combustor. The combination of the two technologies represents an attractive approach to highly efficient, zero-emissions coal-based systems that capture and sequester carbon dioxide.

Relationship to NETL Advanced Power Systems Program:

This program comes under the technology area "Turbines Program".

Primary Project Goal:

Develop and test a 50 MW CES oxy-combustor for operation on coal-derived syngas

Objectives:

The overall objective of the project is the design and demonstration of a pre-commercial oxy-syngas combustor that will enable the commercialization of a high-efficiency coal-based power generation process with near 100% CO_2 capture by 2015. The combustor development program is planned in three phases.

19: NT42652

Project Number: DE-FC26-05NT42652	**Project Title:** Systems Analyses of Advanced Brayton Cycles		
Contacts DOE/NETL Project Mgr.	**Name** Travis Shultz	**Organization** NETL/DOE	**E-Mail** travis.Shultz@netl.doe.gov
Principal Investigator	Professor Scott Samuelsen		
Partners			
Stage of Development	X Basic R&D __ Applied R&D __ Proof of Concept __ Demonstration		

Technical Background:

Advanced improvements to the Brayton Cycle (such as, but not limited to, higher firing temperature, higher pressure ratio, intercooling, reheat, fuel or combustion air augmentation, blade cooling schemes) that will lead to significant performance improvements in coal-based power systems are being identified and assessed.

Since a total systems solution is critical to establishing a plant configuration worthy of significant market interest, a baseline IGCC plant scheme is developed and used to study how alternative process schemes and power cycles might be used and integrated to achieve higher system efficiency. To achieve these design results, the total systems approach taken requires creative integration of the various process units within the plant.

The studies are being sufficiently detailed and documented so that third parties will be able to quickly validate portions or all of the studies. The designs and system studies are based on plants for near zero emissions (including CO_2). Also included in this program are performance evaluations of other advanced technologies such as advanced compression concepts and a fuel cell-based combined cycle. The objective of the fuel cell-based combined cycle task is to identify the desired performance characteristics and design basis for a gas turbine that will be integrated with an SOFC in Integrated Gasification Fuel Cell (IGFC) applications.

Relationship to NETL Advanced Power Systems Program:

This study addresses the advanced turbine project area of the Advanced Power Systems Program.

Primary Project Goal:

The goal is the conceptualization of near zero emission (including CO_2 capture) integrated gasification power plants producing electricity as the principle product. This assessment is being conducted in the context of conceptual design studies (systems studies) that advance state-of-art Brayton cycles and result in coal based efficiencies equivalent to 65% + on natural gas basis (LHV), or approximately an 8-fold reduction in heat rate of an Integrated gasification Combined cycle (IGCC) plant utilizing the H class steam cooled gas turbine.

Objectives:

The main objective is to identify and assess advanced improvements to the Brayton Cycle that will lead to significant performance improvements in coal based gasification plants. Advanced gas turbine based cycles for IGCC applications are identified by a screening analysis and the more promising cycles recommended for detailed systems analysis. The capability of such plants to co-produce H_2 is qualitatively addressed.

Another objective of this systems study it to quantify any performance improvements that may be gained by incorporating advanced CO_2 compression concepts being developed by Ramgen (shock compression) and Southwest Research Institute (isothermal compression).

In the case of the IGFC task, the main objective is met by developing a steady-state simulation of the entire plant and then using dynamic simulations of the hybrid Solid Oxide Fuel Cell (SOFC) / Gas Turbine sub-system to investigate the turbo-machinery performance. From these investigations the desired performance characteristics and a basis for design of turbo-machinery for use in a fuel cell gas turbine power block are developed.

20: FWP FEAA070

Project Number: FEAA070	**Project Title:** Materials Issues in Coal-Derived Synthesis Gas/Hydrogen-Fired Turbines		
Contacts DOE/NETL Project Mgr.	**Name** R. A. Dennis	**Organization** NETL/DOE	**E-Mail** rdennis@netl.doe.gov
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Stage of Development	__ Basic R&D X Applied R&D	__ Proof of Concept	__ Demonstration

Technical Background:

The state-of-the-art gas turbines currently available for use in land-based power generation systems are the result of extensive development work carried out in the 1990's. A critical factor in their development was that, in order to operate at the high turbine entry temperatures (TETs) required for high efficiency, aeroengine technology (i.e., single-crystal blades, thermal barrier coatings, and sophisticated cooling techniques) had to be rapidly scaled up and introduced into these large gas turbines. Even though the design fuel was relatively clean natural gas, there were initial problems with reliability. These problems have been largely overcome following extended development work, so that the high-efficiency gas turbine combined-cycle (GTCC) power generation system is now considered to be a mature technology, capable of achieving high levels of availability. The transition to coal-derived syngas (or hydrogen) as the primary fuel for these machines introduces new challenges in order to accommodate the physical and chemical differences of these fuels, while maintaining efficiency and reliability levels. Differences compared to natural gas in, for instance, calorific value, flame speed, and impurity levels, very likely will require changes in design and materials selection for some of the turbine components.

The high TETs required in the state-of-the-art natural gas-fired turbines necessitate reliable cooling of some components, since the temperature of the combustion gas is higher than the melting temperature of the available hot gas path alloys. The result is that the strongest alloys available (typically single-crystal Ni-based superalloys) are used for the blades and vanes in the first stage, and possibly second stage, of the turbine, and operate essentially at their temperature limits. These components also are provided with complex internal cooling passages, used to maintain the desired metal temperatures. The amount of cooling air must be minimized to maximize engine efficiency, and this is attempted through the application of ceramic, thermal barrier coatings (TBCs) to the affected surfaces. Increasingly, the full functioning of the TBC is essential for the engine to meet performance targets, so that an unprecedented level of materials reliability and consistency of performance is required. Consequently, a major effort is ongoing worldwide to understanding the failure mechanisms of TBCs, with the aim of achieving the degree of predictability needed to allow the confident use of mechanism-based lifing models, and with the hope of eventually attaining the goal of being able to take full advantage in engine design of the temperature decrement provided by a TBC. In parallel with this development, non-destructive evaluation (NDE) techniques are being devised to enable the condition of the coating to be monitored (preferably in-situ) to provide early indication of coating deterioration. A TBC consists of a thin, metallic coating (or bond coating, ~50 μm thick), usually an aluminide [NiAl or (Ni,Pt)Al] formed by diffusion, or a MCrAlY-type overlay (where M can be Ni, Co or NiCo) applied to the superalloy substrate; and a layer of ceramic, typically yttria-stabilized zirconia (usually 125-500 μm thick, though there is strong interest in increased thermal resistivity, hence thicker ceramic layers) applied on top of the bond coating. The purpose of the bond coating is threefold: (i) to provide an anchoring surface for the ceramic layer; (ii) to give oxidation protection (since zirconia allows rapid transport of oxygen); and (iii) to offer some resistance to other forms of corrosion that could include oxidation-sulfidation (from gaseous S contaminants in the combustion products) and hot corrosion (from the presence of deposits of molten alkali sulfates), should the requisite corrodents gain access to the metallic surface if the ceramic layer is breached. The composition of the ceramic layer is optimized for good structural stability and toughness as well as reduced thermal conductivity. Currently, while the reliability of TBC systems has increased significantly, there remains sufficient variability that some TBC systems are as yet insufficiently robust to give predictable performance in the long term in turbines fired by natural gas. The turbine manufacturers have undertaken programs to address the changes needed to provide the capability of firing coal-derived gaseous fuels in their specific turbine designs and, understandably, many of the details of these efforts are considered to be proprietary. The intent of this project at ORNL is to (i) provide an assessment of the key materials issues, and to determine which issues are generic and longer range, or are outside the scope of the manufacturer's programs, and which are amenable to being addressed by research groups outside the manufacturers, and (ii) apply ORNL's expertise and facilities to make progress on appropriate issues.

The main effort in this ORNL project is focused on the evaluation of concepts for maximizing the performance of metallic/bond coatings under the conditions set by combustion of the new fuels [building on advances made in the US DOE's Advanced Turbine Systems (ATS) program]. Also, there are parallel efforts in support of the coating development to describe the corrosive environment and temperature regimes to be encountered by such bond coatings, as a function of fuel type, and so provide realistic performance targets for the coatings. One subtask is aimed at defining the envelope of impurity levels possible from the range of coals, gasification processes, and gas clean-up systems under consideration, to determine if conditions will be encountered under which deposition, erosion, or corrosion of the hot gas path components could occur. In addition, it is of vital importance to know the temperatures, pressures, and residence times that will be experienced by the critical hot gas path components as a function of operating scenarios with syngas or hydrogen. Since the maximum permissible metal temperatures of these components are fixed, the implications for the influences of different fuel characteristics on engine operating parameters (efficiency; power rating), and/or for changes in engine design (cooling; gas flow rates) become highly proprietary, so that there is scant expectation that information on actual metal temperatures along the hot gas path will be made available by the engine manufacturers. The alternative is to develop a realistic, thermodynamic, fluid flow, and heat transfer model of a generic gas turbine that will allow the calculation of credible values of gas parameters (temperature, pressure and composition) and metal temperatures expected to be experienced by the critical hot gas path components. Further, the ability to calculate the temperatures of specific components (including those at interfaces, and the spatial distribution within components), and the extent of change as a function of time (especially, due to degradation of TBCs), provides the basis for calculating parameters that can be directly correlated to component lifetime (such as the rate of interdiffusion between coatings and substrates). This is the goal of another of the ORNL supporting tasks, and is less daunting than at first sight, since there are sufficient mathematical models of various aspects of turbine operation available in the open literature to allow a modular turbine model to be assembled. Nevertheless, a complicating issue is to properly integrate these modules to correctly account for the interconnectivity of the flows of combustion air, fuel, cooling air, hence their effects on heat transfer to the components of interest. There is a further task designed to coordinate the experimental efforts, to ensure that the activities take full account of related developments elsewhere, and to interact with the gas turbine manufacturers and obtain their feedback. To this end, a survey of the materials issues and needs for gas turbines fired by coal-derived syngas or hydrogen was compiled from available open literature and from discussions with the engine manufacturers, and is being published as an ORNL report. The tasks described, and their interconnections, are shown schematically in a diagram in the Project Schedule section.

The expertise brought to this project by ORNL is based on participation by project members in the earlier ATS program, which involved providing technical oversight of materials and manufacturing projects, as well as performing research on key materials issues. A particular interest was optimization of bond coatings to maximize the lifetime of the thermal barrier coatings critical to the successful operation of these advanced turbines. Some of the publications listed below involve examination of the key materials issues that still need to be resolved in order to progress toward that end with advanced, clean natural gas-fired land-based gas turbines, as well as similarities and differences expected from transitioning to syngas-based fuels.

Relationship to NETL Advanced Power Systems Program:

This project is focused on the gas turbines that are the central part of power systems based on integration of coal gasification with gas turbine combined-cycle technology, and addresses the key materials issues that impact the ability to maintain reliable operation at high efficiency when burning fuels such as syngas and hydrogen.

Primary Project Goal:

In broad terms, the primary goal is to define the overall needs for improved or new materials for the reliable operation of gas turbines when fired with coal syngas and H_2-enriched fuel gases, and explore routes for fulfilling the identified needs through computational and experimental methods. The main focus is to maximize the service lifetime of metallic coatings that can be used as bond coatings in TBCs by applying mechanistic understanding of the factors that contribute to the degradation of alloys and coatings in the extreme environments expected in syngas/hydrogen-fired gas turbines.

Objectives:

1. Evaluation of approaches for improved coatings to provide the basis for more robust hot gas path components;
2. Definition of the gaseous environment expected to be encountered by the hot gas path components, leading to development of guidelines for improved syngas impurity specifications to better define syngas cleanup system requirements; and
3. Estimation of the temperatures of components of interest, as well as the gas temperatures and pressures along the hot gas path, to provide realistic materials performance targets.

21:T401.01.06

Project Number: T401.01.06	**Project Title:** Development of Baseline Performance Values for Turbines in Existing IGCC Applications		
Contacts DOE/NETL Project Mgr.	**Name** Patrick Le	**Organization** NETL/DOE/OSAP	**E-Mail** patrick.le@netl.doe.gov
Principal Investigator	Walter Shelton	NETL/DOE/OSAP	walter.shelton@netl.doe.gov
Partners	RDS SUBTASK R401.01.06 RDS Task/Subtask Manager: John Haslbeck (W. Shelton was an employee of RDS during this project)		
Stage of Development	__ Basic R&D X Applied R&D __ Proof of Concept __ Demonstration		

Technical Background:

The U.S. Department of Energy (DOE) Office of Fossil Energy has established projects to develop highly efficient turbines for coal-based fuels in integrated gasification combined-cycle applications. These fuels include coal-derived synthesis gas and pure hydrogen. The projects, with both General Electric and Siemens, have specific performance goals they must strive to attain. In order to ascertain the actual performance improvements that must be realized in these projects to reach the project goals, existing turbine baseline performance must be established. This paper will present the work conducted to establish the baseline performance parameters, and the values of these parameters. Performance parameters and values reported in the open literature will be presented. Parameters that are not available in the literature are also reported and were obtained by using ASPEN PLUS (Aspen Technology, Inc.) and GT-PRO (Thermoflow, Inc.) simulation software.

Relationship to NETL Advanced Power Systems Program:

The project was funded by NETL through the Office of Systems Analysis and Planning (OSAP) to support the objectives of the Advanced Power Systems Program. The project was a task in the site support contract with RDS.

Primary Project Goal:

Based on existing public literature and system studies, the goal was to determine baseline performance values for turbines in existing commercial scale IGCC systems. An additional goal was to project these values for conceptual IGGC plants with carbon capture. Commercial IGCC plants considered were:

- Wabash IGCC
- Tampa (Polk) IGCC
- Ashtabula, IGCC (Nordic Energy Project- proposed 2002)
- Buggenum IGCC (Netherlands)
- Puertollano IGCC (Spain)

Objectives:

The project objectives included:

- Understand existing turbine performance in IGCC
  - Literature survey of available performance data
- Develop detailed operating data with out proprietary information
  - Development of process simulations to determine unknown performance data
- Estimate what might be the state of the art in GT technology for IGCC
  - Develop basis for assessing developers efforts' to meet DOE goals and objectives