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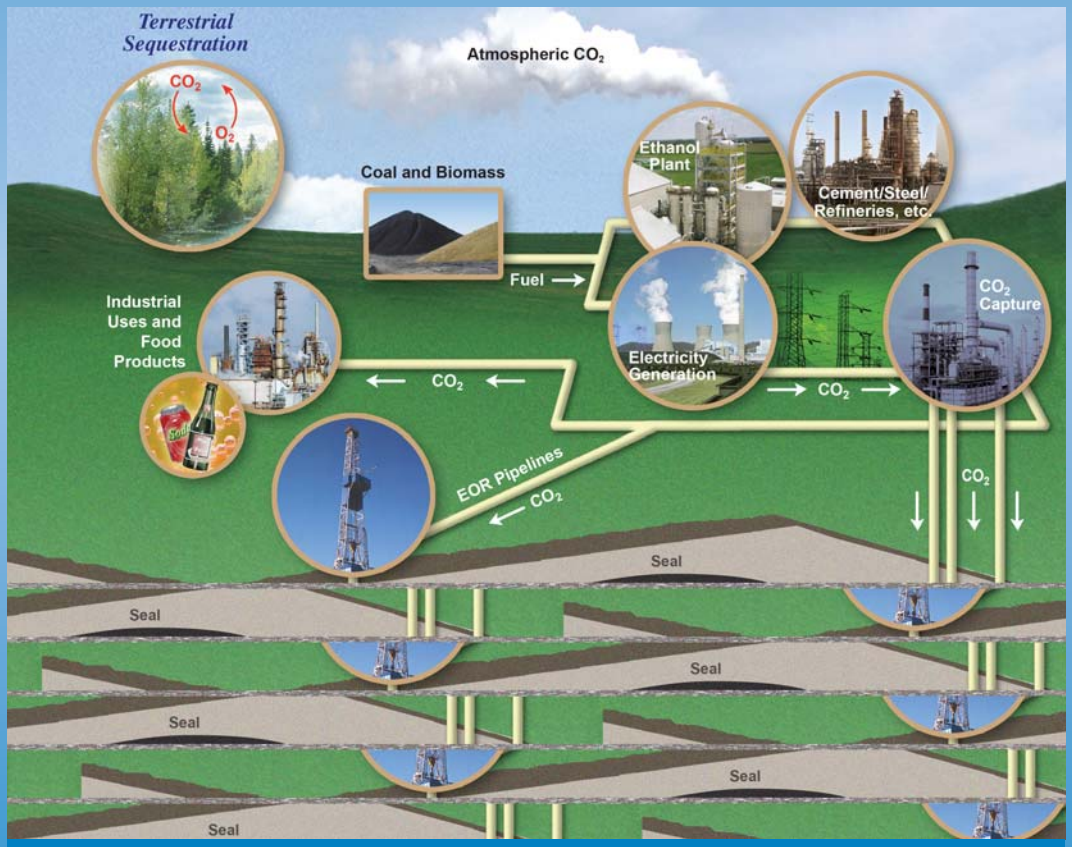
Final Report
2007 Strategic Center for Coal Carbon Sequestration Peer Review Meeting



MEETING SUMMARY AND RECOMMENDATIONS REPORT

Pittsburgh, Pennsylvania
September 17 - 20, 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 CARBON SEQUESTRATION PEER REVIEW MEETING

Pittsburgh, Pennsylvania
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MEETING SUMMARY AND RECOMMENDATIONS REPORT

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EXECUTIVE SUMMARY

The National Energy Technology Laboratory (NETL) is a multi-purpose laboratory owned and operated by the U.S. Department of Energy (DOE) Office of Fossil Energy and is the primary DOE office implementing the Carbon Sequestration Program. The Carbon Sequestration Program undertakes research and development with the goal of developing technologies to substantially reduce greenhouse gas emissions. By 2020, NETL envisions having a technology portfolio of safe, cost-effective, commercial-scale greenhouse gas capture, storage, and mitigation technologies, leading to substantial deployment and market penetration.

NETL's primary Carbon Sequestration research and development objectives are: (1) lowering the cost and energy penalty associated with carbon dioxide (CO_2) capture from fossil fuel production and use; and (2) improving the understanding of factors affecting CO_2 storage permanence, capacity, and safety in geologic formations and terrestrial ecosystems. Once these objectives are met, new and existing power plants and fuel processing facilities in the United States and around the world will have the potential to substantially reduce emissions of CO_2.

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 Carbon Sequestration 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 nine leading government, academic, and industry experts on September 17-20, 2007 to conduct a three-day review of selected Carbon Sequestration research projects supported by NETL. For more on ASME and OMB compliance, see Section I.

Overview of Carbon Sequestration Research Categories

The Review Panel completed reviews of 17 projects. The distribution of projects reviewed is as follows:

- Regional Partnerships 4 projects;
- Carbon Capture 7 projects;
- Geologic Sequestration 1 project;
- Measurement, Monitoring, and Verification 3 projects;
- Non-CO_2 Greenhouse Gas Mitigation 1 project;
- Breakthrough Concepts 1 project.

The following documents were provided to the Review Panel prior to the Peer Review meeting as background information for the Carbon Sequestration Program:

- DOE Strategic Plan (2006);
- Office of Clean Coal Strategic Plan (September 2006);
- Select sections of Office of Clean Coal Multi-Year Program Plan (only Carbon Sequestration); and
- DOE Carbon Sequestration Program Overview.

TABLE ES-1 SUMMARY OF PROJECTS REVIEWED

Order Number	Project Number	Project Title	Lead Organization	Principal Investigator	Total Funding[1]		Project Duration[1]	
					DOE	"Cost Share"	From	To
01	NT41148	Enhanced Coal Bed Methane Production and Sequestration of CO_2 in Unmineable Coal Seams	CONSOL Energy, Inc.	Roy Scandrol	$8,964,176	$4,314,307	21-Sep-01	31-Dec-08
02	NT41620	Capture and Use of Coal Mine Ventilation Air Methane	CONSOL Energy, Inc.	Deborah Kosmack	$1,681,942	$420,486	23-Sep-02	28-Feb-08
03	NT41149	Weyburn CO_2 Monitoring and Storage Project	Petroleum Technology Research Center (PTRC)	Carolyn Preston	$8,000,000	$23,000,000	1-Jun-02	30-Sep-09
04	ORD-07-220641	Storage and Permanence Assessment	NETL	Art Wells	$6,025,000	$0	1-Oct-03	30-Sep-08
05	NT42262	Basic Science of Retention Issues, Risk Assessment Measurement, Monitoring, Verification for Geologic CO_2 Sequestration	Montana State University	Lee Spangler	$7,147,998	$297,304	30-Sep-04	30-Jun-08
06	NT42588	An Assessment of Geological Carbon Sequestration Options in the Illinois Basin - Phase II	Illinois State Geological Survey (ISGS)	Scott Frailey	$15,923,710	$5,514,328	30-Sep-05	30-Sep-09
07	NT42592	Plains CO_2 Reduction (PCOR) Partnership - Phase II	University of North Dakota Energy and Enviromental Research Center (UND-EERC)	Ed Steadman	$82,913,178	$78,967,875	29-Sep-05	30-Sep-17
08	NT42593	West Coast Regional Carbon Sequestration Partnership	California Energy Commission (CEC)	Larry Myer	$10,789,729	$11,534,211	22-Sep-05	29-Sep-09
09	NT42587	Big Sky Regional Carbon Sequestration Partnership - Phase II	Montana State University	Lee Spangler	$11,495,087	$3,673,144	30-Sep-05	30-Sep-09
10	NT42430	Oxygen-Fired CO_2 Recycle for Application to Direct CO_2 Capture from Coal-Fired Power Plants	Southern Research Institute (SRI)	Thomas K. Gale	$863,723	$215,931	27-Sep-05	26-Sep-08
11	NT42748	Pilot-Scale Demonstration of a Novel, Low-Cost Oxygen Supply Process and its Integration with Oxy-Fuel Coal-Fired Boilers	The BOC Group, Inc.	Krish R. Krishnamurthy	$4,906,089	$1,226,524	21-Mar-06	30-Sep-09
12	NT42808	Utah Center for Ultra Clean Coal Utilization	University of Utah	Ronald Pugmire and Adel Sarofim	$2,301,210	$575,303	29-Jun-06	31-Mar-09
13	NT42811	Jupiter Oxycombustion and Integrated Pollutant Removal for the Existing Coal Fired Power Generation Fleet	Jupiter Oxygen Corporation	Mark Schoenfield	$2,055,020	$517,455	28-Sep-06	31-Mar-08
14	NT42122	Design and Evaluation of Ionic Liquids as Novel Absorbents	University of Notre Dame	Edward J. Maginn	$434,076	$0	16-Jul-04	15-Jul-07
15	NT43091	Ionic Liquids: Breakthrough Absorption Technology for Post-Combustion CO_2 Capture	University of Notre Dame	Edward J. Maginn	$2,211,304	$793,861	1-Mar-07	30-Jun-10
16	T401.01.01	Membrane Selection and Placement for Optimal CO_2 Capture from IGCC Power Plants	NETL	Jared Ciferno[2]	$500,000	$0	1-Nov-05	30-Oct-08
17	ORD-07-220614	CO_2 Capture and Separation	NETL	David R. Luebke	$1,008,000	$0	1-Oct-06	30-Sep-07
				TOTALS	$167,220,242	$131,050,729		

Notes:
[1] All funding amounts and project durations obtained through ProMIS on 10-29-07, except where noted (T401.01.01)
[2] Funding amounts and project durations obtained from project summaries submitted by the Principal Investigator.

The total project value of the 17 projects peer reviewed is $298,270,971 of which $167,220,242 (56.1%) is from DOE and $131,050,729 (43.9%) is from cost sharing. The allocation of DOE funding by sub-program in this review is as follows:

Carbon Sequestion Subprogram	***Total Project Value DOE Share***	***FY07 DOE Share***
Regional Partnerships	$121,121,704	$ 19,463,000
Carbon Capture	$ 13,845,346	$ 3,986,000
Geologic Sequestration	$ 8,984,176	$ 237,000
Measurement, Monitoring, and Verification	$ 21,172,998	$ 7,886,000
Non-CO_2 Greenhouse Gas Mitigation	$ 1,681,942	$ 0
Breakthrough Concepts	$ 434,076	$ 224,000
Total	***$167,220,242***	$ 31,796,000

The 17 projects that were the subject of this Peer Review are summarized in Table ES-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 review the technical approach, assess the progress, and 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 eleven-page Project Summary Sheet containing summary information about their project that was subsequently provided to the Review Panel. After reviewing this information, the individual Panel Members submitted questions pertaining to the projects. Copies of the Panel's questions were forwarded to the respective Principal Investigators (PIs), and responsible NETL Project Manager in advance of the meeting. Each 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 17 projects using both a predetermined set of review criteria and written review comments. For each of the 10 Review Criteria, 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 of all 10 Review Criteria for all 17 projects. Projects identified as #14 and #15 were reviewed and "scored" as one project. This was done, at NETL's request because both Projects were performed by the same organization (i.e., University of Notre Dame) and Project #15 was a continuation of the work initiated under Project #14.

FIGURE ES-1

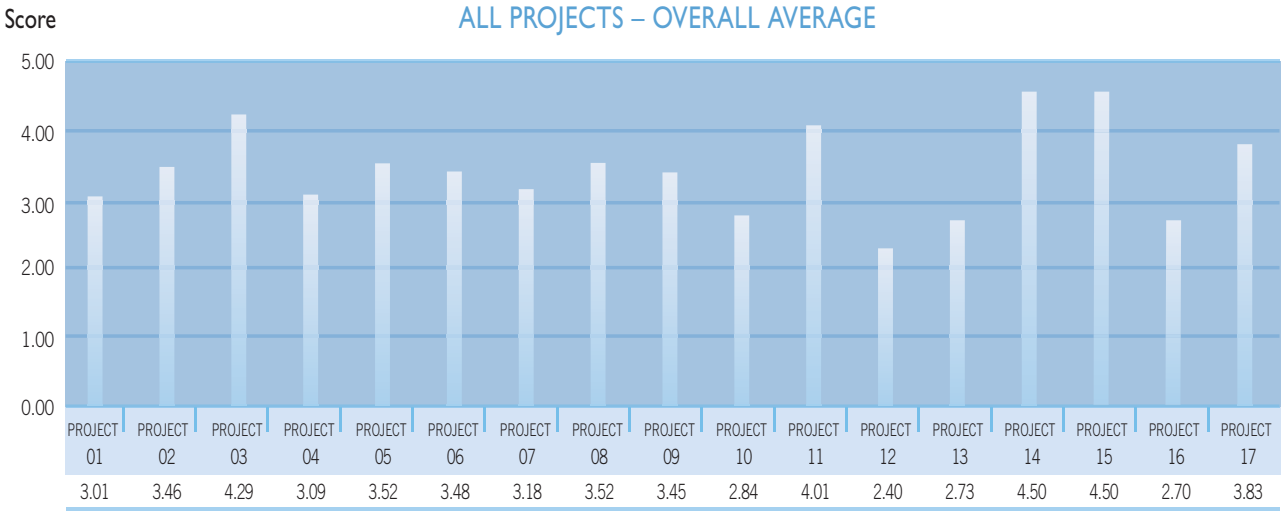

Table ES-2 shows the average, highest individual, and lowest individual score given for each Review Criterion, rank ordered from highest to lowest average score, across all 17 projects reviewed.

Table ES-2 SCORES BY REVIEW CRITERION

Rank	Criterion	Average	Highest	Lowest
1	Scientific and Technical Merit	3.7	5.0	2.8
2	Technical Approach	3.7	5.0	2.6
3	Anticipated Benefits if Successful	3.7	4.8	2.6
4	Rate of Progress	3.4	5.0	2.2
5	Utilization of Government Resources	3.4	4.7	2.6
6	Commercialization Potential	3.3	4.4	2.1
7	Knowledge of Related Research	3.3	4.8	2.1
8	Attention to Constituent's Concerns	3.2	4.3	2.1
9	Possible Adverse Effects Considered	2.9	4.2	1.9
10	Economic Analysis	2.7	4.0	1.7

Table ES-2 illustrates that the average of all the projects scored reasonably well against the ten Review Criterion. They scored "Adequate" or better for 9 out of 10 Review Criterion used in this Review. Only for "Economic Analysis" does the average of all project scores fall below the level of "Adequate."

Key Findings

- Reviewers commented that, overall, they had seen a group of excellent projects.
- The quality of these research projects is helping to provide more accurate answers to questions from the public and the regional carbon sequestration partnerships' outreach programs are rapidly educating the public about carbon sequestration.
- All of the projects reviewed were judged to be "Adequate" for 9 out of 10 Review Criteria considered.
- Most projects were commended for paying more "Attention to Constituent's Concerns."
- Projects, in general, must do a better job on "Economic Analysis."
- Because of the increasingly important role of carbon sequestration in carbon management, the Review Panel recommended accelerating promising projects, as possible, so as to potentially achieve near-term application of carbon sequestration more quickly.

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. Process considerations and recommendations for future project reviews are found in Section V.

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.

VOLUME I. MEETING SUMMARY AND RECOMMENDATIONS

APPENDICES:

I. INTRODUCTION

In 2007, the American Society of Mechanical Engineers (ASME) was invited to provide an independent, unbiased, review of selected projects within the Carbon Sequestration 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 Carbon Sequestration 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 17 projects in the following Carbon Sequestration research categories:

- Regional Partnerships 4 projects;
- Carbon Capture 7 projects;
- Geologic Sequestration 1 project;
- Measurement, Monitoring, and Verification 3 projects;
- Non-CO_2 Greenhouse Gas Mitigation 1 project; and
- Breakthrough Concepts 1 project.

ASME performed this project review work as a subcontractor to Technology & Management Services, Inc. (TMS), a DOE prime contractor. The 17 projects reviewed were selected by NETL. They are reported to represent 79% (on a $ basis) of the Carbon Sequestration project portfolio. Principal Investigators (PIs) submitted an 11-page written summary of their projects, received questions from 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 are summarized and presented to NETL in this report.

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 ASME Research Committee Chair, selects an Executive Committee of senior ASME members that is responsible for reviewing and selecting all members of the Review Panel 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 Carbon Sequestration 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 Carbon Sequestration 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 Peer Review Criteria Forms in closed sessions. ASME collected copies of these forms and used the information contained therein to prepare the final report for the 2007 Peer Review of the Carbon Sequestration Program. 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 Carbon Sequestration Peer Review Meeting and are organized as follows:

II. Summary of Projects Reviewed in the 2007 Carbon Sequestration Peer Review
    Summary description of the 17 projects reviewed.

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

IV. Summary of Key Project Findings
    Summary of key findings gained by looking across all 17 projects.

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

II. SUMMARY OF PROJECTS REVIEWED IN THE 2007 CARBON SEQUESTRATION PEER REVIEW

The projects that were reviewed by the independent ASME Review Panel for the Carbon Sequestration Peer Review were selected by NETL based on the criteria listed below.

- Key or high-value projects within the Carbon Sequestration Program.
- Carbon Sequestration-related projects being conducted by 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% (on a $ basis) of the Carbon Sequestration Program fiscal year budget—consistent with DOE/EERE *Peer Review Guide* (August 2004) for conducting Peer Reviews.

The 17 Carbon Sequestration projects that were reviewed are listed below.

01: DE-FC26-01NT41148

Enhanced Coal Bed Methane Production and Sequestration of CO_2 in Unmineable Coal Seams

CONSOL Energy, Inc.

02: DE-FC26-02NT41620

Capture and Use of Coal Mine Ventilation Air Methane

CONSOL Energy Inc.

03: DE-FC26-01NT41149

Weyburn Carbon Dioxide Sequestration Project

Petroleum Technology Research Centre (PTRC)

04: ORD-07-220641

Storage and Permanence Assessment

NETL Office of Research and Development

05: DE-FC26-04NT42262

Basic Science of Retention Issues, Risk Assessment & Measurement, Monitoring, & Verification for Geologic CO_2 Sequestration

Montana State University

06: DE-FC26-05NT42588

An Assessment of Geological Carbon Sequestration Options in the Illinois Basin - Phase II

Illinois State Geological Survey

07: DE-FC26-05NT42592

Plains CO_2 Reduction (PCOR) Partnership – Phase II

Energy & Environmental Research Center, University of North Dakota

08: DE-FC26-05NT42592

West Coast Regional Carbon Sequestration Partnership (WESTCARB)

California Energy Commission (CEC)

09: DE-FC26-05NT42587

Big Sky Carbon Sequestration Partnership – Phase II

Montana State University

10: DE-FC26-05NT42430

Oxygen-Fired CO_2 Recycle for Application to Direct CO_2 Capture from Coal-Fired Power Plants

Southern Research Institute

11: DE-FC26-06NT42748

Pilot-Scale Demonstration of a Novel, Low-Cost Oxygen Supply Process and its Integration with Oxy-Fuel Coal-Fired Boilers

The BOC Group, Inc.

12: DE-FC26-06NT42808

Utah Center for Ultra Clean Coal Utilization

University of Utah

13: DE-FC26-06NT42811

Jupiter Oxycombustion and Integrated Pollutant Removal for the Existing Coal Fired Power Generation Fleet

Jupiter Oxygen Corporation

14: DE-FG26-04NT42122

Design and Evaluation of Ionic Liquids as Novel CO_2 Absorbents

University of Notre Dame

15: DE-FC26-07NT43091

Ionic Liquids: Breakthrough Absorption Technology for Post-Combustion CO_2 Capture

University of Notre Dame

16:T401.01.01

Membrane Selection and Placement for Optimal CO_2 Capture from IGCC Power Plants

NETL Office of Systems Analysis and Planning

17: ORD-07-220614

Ionic Liquid-Based Membranes for CO_2 Separations in Fuel Gas Applications

NETL Office of Research and Development

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

III. AN OVERVIEW OF THE EVALUATION PROCESS AND RESULTS IN 2007

The ASME team, in cooperation with NETL and with input from the Peer Review panel, enhanced and refined the process used for evaluating the projects selected for the 2007 Carbon Sequestration Peer Review Meeting based on feedback from prior year peer reviews. A copy of the Peer Review Criteria Form and an explanation of the process are provided in detail in Appendix D. A list of the 10 Review Criteria may be found in Table 1 below.

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 17 projects reviewed in the Carbon Sequestration Program. It is impressive that 12 out of 16 (75%) of the projects reviewed from the Carbon Sequestration Program received an average score of 3.0 or higher. (Note: Projects identified as #14 and #15, both conducted by Notre Dame were reviewed and "scored" as one project. Project #15 was the next phase of work that was initiated under Project #14.) The remaining four (25%) of the projects received an average score of between 2.0 and 3.0.

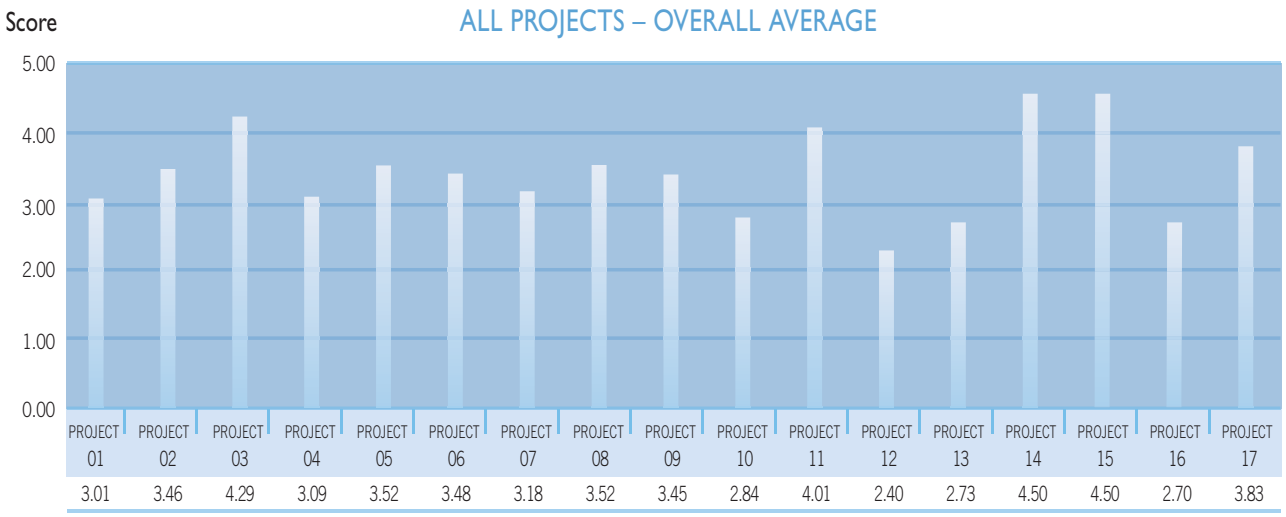

FIGURE 1

It can also be beneficial to look at the average scores for each of the 10 Review Criteria across all 17 projects. The combined average scores for all project criteria are provided in Table 1, rank ordered from highest to lowest:

Table 1 SCORES BY REVIEW CRITERION

Rank	Criterion	Average	Highest	Lowest
1	Scientific and Technical Merit	3.7	5.0	2.8
2	Technical Approach	3.7	5.0	2.6
3	Anticipated Benefits if Successful	3.7	4.8	2.6
4	Rate of Progress	3.4	5.0	2.2
5	Utilization of Government Resources	3.4	4.7	2.6
6	Commercialization Potential	3.3	4.4	2.1
7	Knowledge of Related Research	3.3	4.8	2.1
8	Attention to Constituent's Concerns	3.2	4.3	2.1
9	Possible Adverse Effects Considered	2.9	4.2	1.9
10	Economic Analysis	2.7	4.0	1.7

It is noteworthy that for 9 of the 10 Review Criteria, the overall average Program results were 3.0 or above. The three highest-ranking Review Criteria were: Scientific and Technical Merit, Technical Approach, and Anticipated Benefits if Successful.

The lowest-ranking Review Criterion was Economic Analysis. While some projects did an "effective" economic analysis, other projects did very little. The scoring indicates that economic analysis is an area where the Carbon Sequestration Program should encourage researchers and technology developers to conduct more thorough and frequent cost and performance assessments, consistent with maturity of the technology.

It is also apparent in the table above that, in some cases, it is possible to have a wide variance in scores. Consider, for example, "Economic Analysis." In this case there was a wide variation across projects in how well they did economic analysis. For one project that was successful, the average score on this criterion was 4.0—"Moderately Effective." However, for another project that didn't do economic analysis at all well, the average score was 1.7, below "Ineffective." A wide variation in scores could reflect the different stages of development among the projects reviewed.

IV. SUMMARY OF KEY PROJECT FINDINGS

The purpose of this section is to provide a summary of key findings by looking across all of the individual projects considered at the Peer Review.

General Project Strengths

The Reviewers commented that, overall, they had seen a group of excellent projects. Reviewers who have participated in previous Carbon Sequestration Peer Reviews indicated that the projects have continued to evolve and progress over the last few years to the point where both DOE and the responsible project managers can be very proud of their work to date. The Reviewers also commented that most of the projects are going in the right direction and that these projects are collectively providing a large amount of technical information that will be of considerable use to the larger sequestration issue both nationally and internationally.

The general context of carbon sequestration, into which these research projects fit, is transforming at a very rapid rate. The general public is becoming more and more interested in the subject of carbon sequestration. The quality of these research projects is helping to answer questions from the public more accurately and outreach programs, especially as part of the Regional Partnerships, are educating the public about carbon sequestration in rapidly increasing numbers.

All of the projects in this review were judged to be "Adequate" or better against nine of the 10 Review Criteria considered. The five criteria where projects ranked best were:

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

The Reviewer Panel noted, as a positive trend, that more projects are addressing the "Attention to Constituent's Concerns" Review Criteria. Attention to constituent concerns is critical to the long-term success of carbon sequestration. In previous Peer Reviews, projects have been criticized for not paying enough attention to this area of concern. It is encouraging that more projects are now taking this issue seriously.

Several Reviewers commented on the strength of the NETL in-house research projects reviewed this year, especially the Ionic Liquid-Based Membranes for CO_2 Separations in Fuel Gas Applications project. The internal expertise being developed through this and other in-house projects is a real benefit to NETL. A key advantage of these in-house projects is the ability to transfer expertise among projects quickly through participation in in-house reviews and other forums.

Several Reviewers commented on how "refreshing" it was to hear from PIs who were straightforward in discussing the problems facing them in their research. There are times when PIs need to say "this is not working; we should stop it." Although PIs have been reluctant to say this in the past, at this review, more PIs appeared to be willing to discuss the difficult aspects of their work. This honest self-criticism was very much appreciated by the Reviewers.

General Project Weaknesses

"Economic Analysis" was the Review Criterion where very few projects did well. The overall average score for the 17 projects reviewed was 2.7, which is less than "Adequate." Reviewers always commented favorably when an individual project provided credible economic analysis, but this is still an area where much needs to be done. Too few projects provide any economic analysis and those that do provide it often have flawed assumptions. The Reviewer Panel recommended that this is an area where NETL Project Managers should provide more input to make sure that projects do present economic analysis and that the numbers presented for individual projects are realistic.

Other areas where Reviewer scores were somewhat lower for all projects 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 commercial phase.

Issues for Future Consideration

Several Reviewers pointed out that the general level of interest in carbon sequestration research has increased dramatically over the past several years. Suddenly business and industry are demanding answers to sequestration related topics that are the subject of research projects reviewed here. Reviewers commented and made recommendations throughout the Review where research projects might be accelerated so as to more quickly implement carbon capture and sequestration. Future Project Reviews might consider revising an existing Review Criterion or creating a new one to credit projects that could be accelerated to quicker near-term application.

For example, the Weyburn Carbon Dioxide Sequestration Project site is an excellent test bed for new measurement, monitoring and verification (MMV) technologies being developed.

One Reviewer noted that it is important to train the next generation of researchers by including young scientists and engineers on the project teams. The Reviewer suggested that this special effort to include younger staff could be incorporated into some of the bigger research projects as part of their outreach programs. The training need not only be in technology, but could also include awareness of policy issues and addressing constituent concerns.

V. PROCESS CONSIDERATIONS FOR FUTURE PROJECT 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 at the conclusion of the individual project reviews for the 17 Carbon Sequestration Program projects. Following is a brief summary of ideas recommended for use in planning future Peer Review sessions.

General Process Comments

It was noted that the 10 review criteria are very good and that each point is important; however, not all the points are important for each project. For example, early-stage basic research projects do not need a detailed economic analysis. Also, in very early-stage projects, attention to Constituent's Concerns may not be important. In cases like these, it might be a good idea to include a "Not Applicable" column in the rating criteria.

Consider adjusting the "scoring" format for the large projects, such as the Regional Partnerships, that have so many different elements that are almost projects unto themselves. In these cases, perhaps the various technical activities, such as coal bed sequestration, terrestrial sequestration, and so forth, could be evaluated individually. Alternatively, given the scale and complexity of the Regional Partnerships, consider reviewing them in a separate peer review.

Questions about CO_2 transportation (the pipeline) specifications were raised quite often. For future Carbon Sequestration Peer Review meetings, perhaps DOE could task someone with preparing a list or table of the suggested guidelines for CO_2 transportation.

Presentations

One comment echoed by many Reviewers is that the 11-page project summaries given to the Review Panel prior to the meeting should be a clear and complete representation of the project. The presentation made at the Review meeting itself should not be a surprise to the Reviewers. Also, some Reviewers commented, particularly for the larger, more complex projects (e.g., Regional Partnerships) that the available time for these presentations was too limited, forcing the presenters to focus on only a very narrow portion of the project activities. Other important comments about presentations are:

- The Reviewers would like DOE/NETL to formalize the process for providing Reviewers with answers from the PIs to the questions submitted by Reviewers in response to the 11-page project summaries. If the list of Reviewer questions is lengthy, it may not be possible for the PI to address all these questions in his or her presentation.
- Each project presentation should address the 10 criteria that the Review Panel uses to "score" each project.
- Presenters should practice their presentations so that they do not run out of time and have to skip many of their slides.

It would also be helpful if each project could be charted on the DOE Carbon Sequestration Roadmap. This information could come from DOE; technical researchers should not necessarily be expected to have that level of understanding of the Carbon Sequestration Program.

Pre-Meeting Documentation and Pre-Review Panel Questions

The 11-page, pre-meeting project summary remains a popular document with Reviewers. As discussed above, it should be an accurate summary of the project and should clearly connect to the planned PI presentation that is to follow at the Review meeting. A "disconnect" between the project summary and subsequent PI presentation leads to confusion at the Review Panel and a poor review for the project. Reviewers suggested that Project Managers should take responsibility to see that the 11-page summary and the PI presentation are closely coordinated.

It was originally intended that questions from the Review Panel to the PI, based upon the 11-page project summary, would be used to "fine tune" the PIs presentation at the Panel Review. However, recent experience suggests that the number of questions coming from the Reviewers may be greater than can be managed in the brief presentation time allowed. This issue needs to be addressed in planning future project reviews.

APPENDICES:

APPENDIX A

ASME PEER REVIEW METHODOLOGY

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

As a result of 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 many 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 Carbon Sequestration 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.

Carbon Sequestration 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 Carbon Sequestration Peer Review Executive Committee were as follows:

- **Dr. Adnan Akay, Chair.** Dr. Akay is currently Division Director, Civil, Mechanical, and Manufacturing Innovation at the National Science Foundation (NSF). Prior to NSF, Dr. Akay was professor and head of the Mechanical Engineering Department at Carnegie Mellon University (CMU). Dr. Akay was previously the ASME Vice-President for the Environment and Transportation Group. Dr. Akay has a broad working knowledge of many aspects of combustion engineering.

- **Dr. Allen Robinson.** Dr. Robinson is Associate Professor of Mechanical Engineering at Carnegie Mellon University. He brings to the CO_2 Program Review Executive Committee his special focus on combustion-generated air pollution, biomass combustion, and heat and mass transfer in porous media.

- **Richard T. Laudenat.** Mr. Laudenat is a consultant and was previously a manager with E.S. Boulos, a wholly-owned subsidiary of Northeast Utilities Enterprises, Inc. 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. Mr. Laudenat is well versed on the issue of emissions from electric generating plants.

Carbon Sequestration Peer Review Panel

The Carbon Sequestration 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 Program staff. From these alternatives, the ASME Peer Review Executive Committee oversaw the selection of a nine-member Carbon Sequestration 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 and climate change, chemistry and hydrates, combustion engineering, alloys and membranes, systems engineering and applications, economics, modeling, advanced concepts, petroleum engineering, resource recovery, risk assessment, advanced biology and methane, and electrochemistry.

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 Power Point format with hard-copy handouts of these slides provided to the Reviewers at the beginning of the meeting.

Project Presentations, Evaluations, and Discussion

At the Carbon Sequestration 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 three-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. The following 10 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. The 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.

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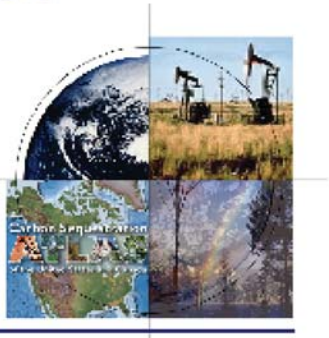

AGENDA

Monday, September 17, 2007

- Closed Session -

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

4:00 - 6:00 p.m. **Carbon Sequestration Peer Review Panel Kick Off Meeting**
- Review of ASME Process - Michael Tinkleman/Kim Hart, ASME
- Meeting Logistics/Completion of Forms - Steven Ostheim/Charles Schmidt, TMS
- Role of NETL - José Figueroa, NETL

Overview of the Carbon Sequestration Program
- Sean Plasynski, Carbon Sequestration Technology Manager, NETL

6:30 - 7:30 p.m. **Registration and Welcome Reception**

Tuesday, September 18, 2007

7:00 - 8:00 a.m. Continental Breakfast

8:00 - 8:30 a.m. *Project # 41148* - Sequestration of Carbon Dioxide Gas in Coal Seams - *Roy Scandrol*, **CONSOL Energy, Inc.**
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 # 41620* - Capture and Use of Coal Mine Ventilation Air Methane - *Deborah Kosmack*, **CONSOL Energy, Inc.**
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 # 41149* - Weyburn Carbon Dioxide Sequestration Project - *Ray Knudsen*, **Natural Resources Canada - CANMET**
11:10 - 11:30 a.m. Q&A
11:30 - 11:50 a.m. Discussion, evaluation, and written comments

11:50 - 1:00 p.m. **Lunch (on your own)**

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Tuesday, September 18, 2007

1:00 - 1:30 p.m.	*Project # ORD -07-220641* - Storage and Permanence Assessment - *Art Wells*, **National Energy Technology Laboratory**
1:30 - 1:50 p.m.	Q&A
1:50 - 2:10 p.m.	Discussion, evaluation, and written comments
2:10 - 2:15 p.m.	Set-up/Transition allowance between presentations
2:15 - 2:45 p.m.	*Project # 42262* - Basic Science of Retention Issues, Risk Assessment & Measurement, Monitoring & Verification for Geologic CO_2 Sequestration - *Lee Spangler*, **Montana State University**
2:45 - 3:05 p.m.	Q&A
3:05 - 3:25 p.m.	Discussion, evaluation, and written comments
3:25 - 3:40 p.m.	**BREAK**
3:40 - 4:30 p.m.	*Project # 42588* - An Assessment of Geological Carbon Sequestration Options in the Illinois Basin - Phase II - *Scott Frailey*, **Illinois State Geological Survey**
4:30 - 4:50 p.m.	Q&A
4:50 - 5:15 p.m.	Discussion, evaluation, and written comments

Wednesday, September 19, 2007

7:00 - 8:00 a.m.	Continental Breakfast
8:00 - 8:50 a.m.	*Project # 42592* - Plains CO_2 Reduction Partnership - Phase II - *Ed Steadman*, **University of North Dakota Energy and Environmental Research Center**
8:50 - 9:10 a.m.	Q&A
9:10 - 9:35 a.m.	Discussion, evaluation, and written comments
9:35 - 9:50 a.m.	**BREAK**
9:50 - 10:40 a.m.	*Project # 42593* - West Coast Regional Carbon Sequestration Partnership - *Larry Myer*, **California Energy Commission**
10:40 - 11:00 a.m.	Q&A
11:00 - 11:25 a.m.	Discussion, evaluation, and written comments
11:25 - 12:15 p.m.	**Lunch (on your own)**
12:15 - 1:05 p.m.	*Project # 42587* - Big Sky Regional Carbon Sequestration Partnership - Phase II - *Lee Spangler*, **Montana State University**
1:05 - 1:25 p.m.	Q&A
1:25 - 1:50 p.m.	Discussion, evaluation, and written comments
1:50 - 1:55 p.m.	Set-up/Transition allowance between presentations

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Wednesday, September 19, 2007

1:55 - 2:25 p.m.	*Project # 42430* - Oxygen-Fired CO_2 Recycle for Applications to Direct CO_2 Capture from Coal-Fired Power Plants - *Thomas K. Gale*, **Southern Research Institute**
2:25 - 2:45 p.m.	Q&A
2:45 - 3:05 p.m.	Discussion, evaluation, and written comments
3:05 - 3:20 p.m.	**BREAK**
3:20 - 3:50 p.m.	*Project # 42748* - Pilot-Scale Demonstration of Novel, Low-Cost Oxygen Supply Process and its Integration with Oxy-Fuel Coal-Fired Boilers - *Krish R. Krishnamurthy*, **The BOC Group, Inc.**
3:50 - 4:10 p.m.	Q&A
4:10 - 4:30 p.m.	Discussion, evaluation, and written comments
4:30 - 4:35 p.m.	Set-up/Transition allowance between presentations
4:35 - 5:05 p.m.	*Project # 42808* - Utah Center for Ultra Clean Coal Utilization - *Kerry E. Kelly*, **University of Utah**
5:05 - 5:25 p.m.	Q&A
5:25 - 5:45 p.m.	Discussion, evaluation, and written comments

Thursday, September 20, 2007

7:00 - 7:30 a.m.	Continental Breakfast
7:30 - 8:00 a.m.	*Project # 42811* - Jupiter Oxycombustion and Integrated Pollutant Removal for the Existing Coal Fired Power Generation Fleet - *Mark Schoenfield*, **Jupiter Oxygen Corporation**
8:00 - 8:20 a.m.	Q&A
8:20 - 8:40 a.m.	Discussion, evaluation, and written comments
8:40 - 8:45 a.m.	Set-up/Transition allowance between presentations
8:45 - 9:30 a.m.	*Project # 42122* - Design and Evaluation of Ionic Liquids as Novel Absorbents **and** *Project # 43091* - Ionic Liquids: Breakthrough Absorption Technology for Post-Combustion CO_2 Capture - *Edward J. Maginn*, **University of Notre Dame**
9:30 - 9:50 a.m.	Q&A
9:50 - 10:15 a.m.	Discussion, evaluation, and written comments
10:15 - 10:30 a.m.	**BREAK**
10:30 - 11:00 a.m.	*Project # T401.01.01* - Membrane Selection and Placement for Optimal CO_2 Capture from IGCC Power Plants - *Jared Ciferno*, **National Energy Technology Laboratory**
11:00 - 11:20 a.m.	Q&A
11:20 - 11:40 a.m.	Discussion, evaluation, and written comments

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THURSDAY, SEPTEMBER 20, 2007

11:40 - 12:30 p.m.	**Lunch (on your own)**
12:30 - 1:00 p.m.	*Project # ORD-07-220614* - CO_2 Capture and Separation - *David R. Luebke*, **National Energy Technology Laboratory**
1:00 - 1:20 p.m.	Q&A
1:20 - 1:40 p.m.	Discussion, evaluation, and written comments
1:40 - 1:45 p.m.	**BREAK**
1:45 - 3:15 p.m.	Final Comments on Carbon Sequestration Projects by Reviewers and Overall Meeting Wrap-up

APPENDIX C

PEER REVIEW PANEL MEMBERS

After reviewing the wide range of scientific and engineering related issues represented by the 17 projects to be reviewed, the CRTD staff and the ASME Peer Review Executive Committee in cooperation with the NETL Project Manager developed the following list of "Areas of Expertise" that would need to be represented by the 2007 Carbon Sequestration Peer Review Panel:

Areas of Expertise:

- Modeling
- Chemistry and Hydrates
- Advanced Concepts
- Petroleum Engineering
- Systems Engineering and Applications
- Economics
- Environment
- Resource Recovery
- Combustion Engineering
- Policy and Climate Change
- Risk Assessment
- Electrochemistry
- Alloys and Membranes
- Advanced Biology and Methane

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 and a number of new submissions from a limited call to ASME members with relevant experience, and from DOE.

Appropriate resumes were then submitted to the Carbon Sequestration Peer Review Executive Committee for review. The following nine members were selected for the 2007 Carbon Sequestration Peer Review Panel:

- Dr. John R. Benemann, Consultant
- Dr. Garry D. Brewer, Yale University
- Dr. John F. Clarke, US Department of Homeland Security
- Dr. Robert M. Enick, University of Pittsburgh
- Dr. John R. Kitchin, Carnegie Mellon University
- Dr. Charles A. Miller, US Environmental Protection Agency

- Mr. Bruce Reynolds, Idaho National Laboratory
- Dr. David Thomas, Consultant
- 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 three 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 CARBON SEQUESTRATION PEER REVIEW PANEL MEMBERS

John R. Benemann, Ph. D

Dr. Benemann is currently a consultant with Benemann Associates. He has worked in the area of biofuels, greenhouse gas abatement, and environmental biotechnologies for more than 30 years. Over the past decade, he has attended numerous international conferences and presented well over 100 invited lectures on biofuels, biotechnology, greenhouse gas abatement, biogas production, biohydrogen, microalgae fuels production, and related topics. Dr. Benemann was instrumental in initiating several major research and development (R&D) programs in greenhouse gas abatement including the Coal-Biomass Co-Firing Program carried out by EPRI in the 1990s and, through the not-for-profit Institute of Environmental Management which he founded, the Yolo County "Controlled Bioreactor Landfill" Project (1990 – present). And for the past five years, he has managed the International Network on Biofixation of CO_2 and Greenhouse Gas Abatement with Microalgae, which operates within the International Energy Agency Greenhouse Gas R&D Programme (Cheltenham, England). Dr. Benemann has pioneered the field of biological hydrogen (H_2) production and is an expert in the area of biofuels, from the fundamentals of photosynthetic efficiency, to production and utilization of biofuels using microalgae and other plants. Dr. Benemann earned a Bachelor's Degree in Chemistry and a Doctorate in Biochemistry from the University of California, Berkeley.

Garry D. Brewer, Ph.D

Dr. Brewer is currently the Frederick K. Weyerhaeuser Professor of Resource Policy and Management for the Schools of Management and Forestry and Environmental Studies at Yale University. He returned to this chair in July 2001 after a 10-year hiatus. During those 10 years, Dr. Brewer had a series of other responsibilities including appointments as Professor of Environmental Policy and Management in Berkeley's Energy and Resources Group (ERG); Dean of the University of California's Extension; the King Carl XVI Gustaf Professor of Environmental Sciences at the Royal Institute of Technology in Stockholm (at the invitation and appointment of His Majesty, King Carl XVI Gustaf of Sweden); Professor of Business Administration in the University of Michigan Business School; and Professor of Resource Policy and Management in Michigan's School of Natural Resources and Environment. He is the author, coauthor, or editor of 10 books and over 195 professional publications on a wide range of topics including contributions on organizational complexity and behavior, computer applications to social and national security problems, political and economic development, forecasting and strategic planning, and environmental management and resource matters. Dr. Brewer earned a Bachelor's degree in Mathematical Economics from the University of California, Berkeley, a Master of Science in Public Administration (development) at San Diego State University, and his Master of Philosophy and Doctorate (with distinction) from Yale University.

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 the 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.

Robert M. Enick, Ph.D

Dr. Enick is currently Chairman and Bayer Professor of the Chemical and Petroleum Engineering Department of the University of Pittsburgh. He has been with the university since 1985 and is one of the 24 faculty fellows from the University of Pittsburgh, Carnegie Mellon University, and West Virginia University involved in the Department of Energy, National Energy Technology Laboratory (NETL), Oak Ridge Associated Universities Faculty Participation Program. Dr. Enick's recent project work under this program has included "Separation of Hydrogen (H_2) from Water-Gas Shift Gases using Palladium and Copper (PdCu) Membranes," "Investigation of Carbon Dioxide (CO_2)-Selective Polymeric Membranes," and "CO_2 and H_2 Membranes." In 2007, he was recognized as a National Energy Technology Laboratory (NETL) Institute for Advanced Energy Solutions (IAES) Faculty Fellow. Dr. Enick's areas of specialization are high-pressure phase behavior, supercritical fluid technology, CO_2-soluble compounds, and mathematical modeling of flow in porous media. His recent consulting projects included investigating high-pressure viscosity measurements of CO_2-soluble compounds. Dr. Enick is the author of a recently published book and many refereed journal papers. He earned a Bachelor's Degree in Chemical Engineering with Petroleum Option, Master's Degrees in both Petroleum Engineering and Chemical Engineering, and his Doctorate in Chemical Engineering from the University of Pittsburgh.

John R. Kitchin, Ph.D

Dr. Kitchen currently holds the positions both of Assistant Professor, Department of Chemical Engineering and Courtesy Assistant Professor, Department of Materials Science and Engineering at Carnegie Mellon University (CMU) in Pittsburgh, Pennsylvania. Prior to this he was an Alexander von Humboldt Postdoctoral Research Fellow at the Fritz Haber Institut in Berlin, Germany. Dr. Kitchen's main areas for research include discovering new electrocatalytic materials for proton exchange membrane (PEM) hydrogen fuel cell cathodes and methanol reduction anodes; preparing and characterizing alloy electrocatalysts for use in fuel cell electrocatalyst applications; and achieving ab initio, multiscale modeling of alloy surfaces. He has co-authored numerous publications related to his research including two recent papers, one entitled *"Trends in the chemical properties of early transition metal carbide surfaces: A density functional study"* and the other entitled "Trends in the exchange current for hydrogen evolution." Dr. Kitchin earned a Bachelor of Science degree in Chemistry (summa cum laude) at North Carolina State University and then went on gain his Master of Science degree in Materials Science and Engineering and his Doctorate in Chemical Engineering from the University of Delaware.

Charles A. Miller, Ph.D, P.E.

Dr. Miller is a senior project engineer with the US Environmental Protection Agency (EPA), National Risk Management Research Laboratory (NRMRL) in Research Triangle Park, North Carolina. In over 16 years at NRMRL, his key technical activities have included Characterization of Particulate Matter from Combustion Sources, which involves evaluating particle size distributions and size-specific trace element concentrations in particulate from the combustion of fuel oil, pulverized coal, and diesel exhaust; Assessment of Science Needs for Accountability-Based Air Quality Management, where he was the lead author of the Emissions chapter of the NARSTO Assessment – NARSTO is a public/private partnership dedicated to improving air quality in North America; and Assessment of Air Emissions Inventories, where he was the lead author of the Recommendations chapter for NARSTO Emission Inventory Assessment. Dr. Miller is currently the NRMRL representative for the EPA Office of Research and Development (ORD) Laboratory Research Plan Development, a member of the National Exposure Research Laboratory (NERL) Air Research Implementation Steering Committee, and on the scientific and technical advisory and review committees for the New York State Energy Research and Development Authority and the California Air Resources Board. Among many awards and honors, he was awarded the EPA Gold Medal for Exceptional Service for his role on the International NO_x Control Reburn Team in 2001. Dr. Miller earned both his Bachelor of Science and Master of Science degrees in Mechanical Engineering from the University of Arizona, and his Doctorate in Mechanical Engineering from North Carolina State University. He is also a registered Professional Engineer in North Carolina.

Bruce Reynolds, MSChE

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 is 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.

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.

Raymond L. Zahradnik, Ph.D

Dr. Zahradnik is a consultant and partner in Appalachian-Pacific LLC. 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. 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

U. S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
2007 CARBON SEQUESTRATION
PEER REVIEW MEETING

SEPTEMBER 17 TO 20, 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 criteria are provided on page 4. For each criterion, select the appropriate rating by typing an "X" in the applicable cell. Definitions for the five ratings criteria are provided on page 1.

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

CRITERION		***RATING CRITERIA***				
(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.

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APPENDIX E

CARBON SEQUESTRATION PROJECT SUMMARIES

Presentation ID Number	*Project Number*	*Title*
01	DE-FC26-01NT41148	Enhanced Coal Bed Methane Production and Sequestration of CO_2 in Unmineable Coal Seams
02	DE-FC26-02NT41620	Capture and Use of Coal Mine Ventilation Air Methane
03	DE-FC26-01NT41149	Weyburn Carbon Dioxide Sequestration Project
04	ORD-07-220641	Storage and Permanence Assessment
05	DE-FC26-04NT42262	Basic Science of Retention Issues, Risk Assessment & Measurement, Monitoring, & Verification for Geologic CO_2 Sequestration
06	DE-FC26-05NT42588	An Assessment of Geological Carbon Sequestration Options in the Illinois Basin – Phase II
07	DE-FC26-05NT42592	Plains CO_2 Reduction (PCOR) Partnership Phase II
08	DE-FC26-05NT42593	West Coast Regional Carbon Sequestration Partnership (WESTCARB)
09	DE-FC26-05NT42587	Big Sky Carbon Sequestration Partnership – Phase II
10	DE-FC26-05NT42430	Oxygen-Fired CO_2 Recycle for Application to Direct CO_2 Capture from Coal-Fired Power Plants
11	DE-FC26-06NT42748	Pilot-Scale Demonstration of a Novel, Low-Cost Oxygen Supply Process and its Integration with Oxy-Fuel Coal-Fired Boilers
12	DE-FC26-06NT42808	Utah Center for Ultra Clean Coal Utilization
13	DE-FC26-06NT42811	Jupiter Oxy-combustion and Integrated Pollutant Removal for the Existing Coal Fired Power Generation Fleet
14	DE-FG26-04NT42122	Design and Evaluation of Ionic Liquids as Novel CO_2 Absorbents
15	DE-FC26-07NT43091	Ionic Liquids: Breakthrough Absorption Technology for Post-Combustion CO_2 Capture
16	T401.01.01	Membrane Selection and Placement for Optimal CO_2 Capture from IGCC Power Plants
17	ORD-07-220614	Ionic Liquid-Based Membranes for CO_2 Separations in Fuel Gas Applications

01: DE-FC26-01NT41148

Project Number: DE-FC26-01NT41148	***Project Title:*** Enhanced Coal Bed Methane Production and Sequestration of CO_2 in Unmineable Coal Seams		
Contacts DOE/NETL Project Mgr.	***Name*** William O'Dowd	***Organization*** U.S.DOE/NETL	***E-Mail*** ODOWD@NETL.DOE.GOV
Principal Investigator	Roy Scandrol	CONSOL Energy Inc.	royscandrol@consolenergy.com
Partners	N/A		
Stage of Development	__Basic R&D	__ Applied R&D	X Proof of Concept __Demonstration

Technical Background:

Unmineable coal seams are considered to be a major potential repository for sequestered CO_2. Simultaneous production of coalbed methane (CBM) and CO_2 sequestration (enhanced CBM, or ECBM, production) has the potential to offset the costs of sequestration. In most of the mature CBM fields (e.g., the Southern and Central Appalachian and San Juan Basins), vertical wells stimulated by hydrofracturing serve as production wells. This technique is not useful in the Northern Appalachian Basin because the roof and floor strata are too weak to contain the fractures. Unstimulated vertical wells require very close spacing, driving costs up and making CBM production (and sequestration) very expensive. Recent advances in downhole instrumentation and drill-bit guidance technology make it feasible to drill horizontal wells into thin and undulating coal seams from the surface. Such slant-hole and other horizontal drilling techniques permit much wider spacing of wells, and may greatly improve the economics of CBM production and CO_2 sequestration, especially in fields that cannot be stimulated by hydrofracturing. This project is a proof-of-concept test of using horizontal drilling techniques to produce CBM and sequester CO_2 in an unmineable coal seam in the Northern Appalachian Basin.

Relationship to NETL Carbon Sequestration Program:

This project is part of the "Core R&D", "Carbon Storage", "CO_2 Storage in Geologic Formations", "Deep Coal Seams" area of the *Carbon Sequestration Technology Roadmap and Program Plan 2007.*

Primary Project Goal:

The primary goal of this project is to perform the first-ever sequestration of carbon dioxide and simultaneous ECBM production using horizontal drilling technology in an unmineable coal seam in the Northern Appalachian Basin and to evaluate its effectiveness and the conceptual economics of a commercial-scale project.

Objectives:

The project objectives include: Demonstrate the use of horizontal drilling technology for CBM production from two relatively thin, undulating coal seams in the Northern Appalachian Basin. Attempt to drill a pattern resembling a square with 3,000 ft. legs in a mineable and an underlying unmineable seam, and drill wells with four 1000-ft legs in the center of the square of the unmineable seam. After the in-place CBM resource has been partially drawn down, use the central wells to inject about 20,000 ton of carbon dioxide into the unmineable seam for sequestration and for simultaneous ECBM production from the peripheral wells. Determine the behavior of the carbon dioxide, the coal seam during injection, and the impact of the injection on CBM production. Monitor the behavior of the sequestered CO_2.and any effects on the surface and subsurface.

02: DE-FC26-02NT41620

Project Number: DE-FC26-02NT41620	***Project Title:*** Capture and Use of Coal Mine Ventilation Air Methane		
Contacts DOE/NETL Project Mgr.	***Name*** William J. O'Dowd	***Organization*** NETL	***E-Mail*** william.odowd@netl.doe.gov
Principal Investigator	Deborah A. Kosmack CONSOL Energy Inc. R&D deborahkosmack@consolenergy.com		
Partners	Kenneth P. Zak	MEGTEC Systems	kzak@megtec.com
Stage of Development	__Basic R&D	__ Applied R&D	X Proof of Concept __Demonstration

Technical Background:

The Vocsidizer regenerative thermal oxidizer is a proven system for destruction of volatile organic compounds with over 600 installations worldwide in industrial applications. Megtec is one of the largest suppliers of oxidizers in the world and builds between 100-150 oxidizers per year (15-20 of the VOCSIDIZER style). MEGTEC has experience in treating slip-stream ventilation air methane (VAM) emissions from small pilot tests in the U.K. and Australia. The VOCSIDIZER consists of a bed of ceramic medium contained in an airtight steel container resting on a sturdy steel frame. Above and below the bed are air plenum chambers to provide even distribution of the inlet air. The granular ceramic bed material ensures optimum flow and temperature distribution over the bed. Electrical heating elements are placed in the bed to obtain the required start-up temperature of ca. 1000 C. The process fan at the inlet side of the VOCSIDIZER forces the feed air via dampers into the plenum and through the preheated bed where the air is heated to a temperature at which methane is completely oxidized. The thermal energy released during methane oxidization is recovered by the bed media as the air moves to the outlet side of the bed. Thermocouples in the bed are tied to the programmable logic controller (PLC) system that monitors the temperature profile of the bed and the movement of the high-temperature zone, which moves towards the outlet of the ceramic bed. To maintain the high-temperature zone within the ceramic bed, switching valves reverse the air flow through the bed periodically. The PLC program optimizes valve switching intervals using time and temperature to maximize energy efficiency. After the valves have switched and reversed the direction of air flow through the bed, the energy that was recovered and stored in one side of the bed heats the incoming process air to oxidation temperature. The high-temperature zone in the bed now moves toward the new outlet and the process repeats. In operation, the VOCSIDIZER typically changes air flow direction through the bed every 120 seconds. The reaction zone at the oxidation temperature is sustained in the center of the bed by optimizing the regenerative heat exchange between the ventilation air and the ceramic bed. Because the unit has rugged construction, few moving parts, and advanced controls, it is expected that the system will require little maintenance and maintain reliable emission control performance. The expected methane conversion is 95%. This technology is capable of sustaining oxidation of methane at concentrations from 0.3 to 1.2% in air.

Therefore, it is well suited to oxidize ventilation air methane into CO_2 and water, thus reducing its global warming potential by about 87%.

Relationship to NETL Carbon Sequestration Program:

The Carbon Sequestration Program focuses on technology with great potential for reducing greenhouse gas emissions. Methane is the second most important non-water greenhouse gas, and it has a global warming potential 21 to 23 times greater than CO_2. Coal mining is a major source of methane emissions and ventilation air methane is the greatest source of methane releases from coal mining. The project is designed to evaluate the potential for the VOCSIDIZER technology to eliminate those methane emissions and to evaluate the possibility of integrating methane abatement with energy production.

Primary Project Goal:

The CONSOL team will conduct an eight-month field test of a commercial-size MEGTEC VOCSIDIZER oxidization system (30,000 cfm), interfaced with an inactive coal mine, at methane concentrations representative of mine ventilation air methane, and will evaluate the potential of the system for deployment on coal mines to reduce methane emissions and to produce energy.

Objectives:

The CONSOL team proposes to demonstrate the capture and use of simulated coal mine ventilation air methane through use of a commercial scale Thermal Flow Reversal Reactor (TFRR) system. The objectives are to: 1) design an effective interface between the TFRR and a mine ventilation system that does not compromise mine safety, 2) conduct a field test to evaluate the use of the device to convert the low and variable concentrations of methane contained in the coal mine ventilation air (simulated by diluted coal mine methane) to carbon dioxide effectively and economically, and 3) determine the quantity of useful energy that can be economically produced when processing ventilation air from a working coal mine and perform an engineering/economic evaluation of the concept.

03: DE-FC26-01NT41149

Project Number: DE-FC26-01NT41149	***Project Title:*** Weyburn Carbon Dioxide Sequestration Project		
Contacts DOE/NETL Project Mgr.	***Name*** Lynn Brickett	***Organization*** NETL-DOE	***E-Mail*** Lynn.Brickett@netl.doe.gov
Principal Investigator	Carolyn Preston Ray Knudsen	PTRC PTRC	Carolyn.Preston@ptrc.ca Ray.Knudsen@ptrc.ca
Partners	See listing of current Sponsors (government & industry) and research		
Stage of Development	__Basic R&D	__ Applied R&D	__ Proof of Concept X_Demonstration

Technical Background:

This project focuses on demonstrating the feasibility of CO_2 geological storage in mature oil and gas reservoirs. The technical research is being conducted in conjunction with two commercial CO_2 EOR projects in the Weyburn and Midale oil fields in southeast Saskatchewan. The first phase, conducted over the period 2000-2004, was based on the Weyburn field operated by EnCana Oil & Gas Partnership. Apache Canada, operator of the adjacent Midale field joined the final phase of the project and started CO_2 injection in the 3rd quarter 2005. This final phase will include a 3-4 year research program. These Enhanced Oil Recovery (EOR) projects are injecting anthropogenic CO_2 from a coal gasification facility located near Beulah, North Dakota. This project is unique due to the comprehensive knowledge of pre-injection reservoir conditions as a result of the extensive historical database of geological & engineering information.

Relationship to NETL Carbon Sequestration Program:

This project is part of the "Core R&D" and "Carbon Storage" area of the *Carbon Sequestration Technology Roadmap and Program Plan 2007*. This project is endorsed by the Carbon Sequestration Leadership Forum.

Primary Project Goal:

- Demonstrate feasibility of long term geological storage of CO_2 in oil reservoirs.
- Use the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project (Final Phase) as the leading project for developing the necessary technical and operating information to guide regulatory policy on EOR-based CO_2 Geological Storage projects.
- Provide sound fact based information to the public and policy and decision makers regarding CO_2 geological storage.

Objectives: Strategic Objectives & Deliverables – Final Phase

Technical:

- Develop a Best Practices Manual for the implementation of practical, safe and reliable EOR-based CO_2 geological storage projects at prospective field sites in Canada, the USA and internationally. Include clear and quantifiable deliverables (Quantification) and address long term storage risks and monitoring requirements to mitigate such risks.

Regulatory and Public Communication:

- Develop a Communication Plan for demonstrating and affirming to all stakeholders the safety and reliability of this method of GHG management for mitigating climate change.
- Foster the adoption of science and engineering-based government regulations for this emerging industry.
- Be mindful that US DOE (NETL) has to consult with other groups within US DOE in this area.

Policy Development:

- Develop credible validation methods (to be included in the Best Practical Manual) of CO_2 volumes stored, to support operators' applications to qualify for CO_2 credits
- Guide the development of legal agreements that would facilitate and encourage commercialization of intellectual property (IP) accruing from technology development to the benefit of the Sponsors
- Work towards enhancing the reputation of the Sponsors in meeting the challenge of GHG management, through demonstrated world leadership in the development of this environmental technology.

04: ORD-07-220641

Project Number: ORD-07-220641	***Project Title:*** Storage and Permanence Assessment		
Contacts DOE/NETL Project Mgr.	***Name***	***Organization***	***E-Mail***
Principal Investigator	Arthur Wells	USDOE/NETL	arthur.wells@netl.doe.gov
Partners			
Stage of Development	__Basic R&D	X_ Applied R&D	__ Proof of Concept __ Demonstration

Technical Background:

For carbon sequestration to be successful in reducing greenhouse gas emissions, it must be safe, predictable, reliable, measurable, and verifiable. It will be necessary to assure essentially permanent sequestration that has been verified and validated by field tested methodologies. Many of the available techniques for measuring leakage to the surface are relatively new and not rigorously tested under field conditions by us or others. They have poorly defined precision and accuracy, limits of detection, linear dynamic ranges, and unknown interferences. These techniques must be applicable in any type of terrain including mountainous, hilly, flat, rocky, forested, grassy, soil, sand, wet, dry and over water. Techniques that simultaneously measure and quantify CO_2 and light hydrocarbons in both soil-gas and in the atmosphere are needed. The techniques should be able to measure CO_2 leakage from storage reservoirs at rates as low as 0.01% per annum and at much higher rates, as well as light hydrocarbon leak rates that range from very low to very high. Successfully reaching these goals will require that MMV technologies be integrated into validated statistical models and computational codes for predicting and interpreting monitoring data.

Another issue that is important to storage permanence is the existence of well bores. Some potential sequestration reservoirs have been drilled through thousands of times and many of these old wells are abandoned. Methods to locate and evaluate these wells, while not strictly an MMV technology, will be needed. The long-term interaction of CO_2 and well bore cement and its potential impact on existing wells is also an area of concern.

Relationship to NETL Carbon Sequestration Program:

Monitoring, Mitigation, and Verification (MMV)

Primary Project Goal:

NETL seeks to develop, test and validated a suite of reliable, low-cost geochemical and geophysical monitoring technologies and related statistical and modeling capabilities that can detect and quantify a leak rate of less than 0.01% per year or higher to verify the integrity of geologically sequestered CO_2. These technologies must be generally acceptable to the public and useful to permitting agencies and to the carbon trading market.

Objectives:

Our approach integrates near-surface monitoring of CO_2 flux, injected tracers, shallow aquifer chemistry, and natural tracers such as radon and light hydrocarbons with statistical analyses of network design and flow simulations to interpret both near-well and more distant migration patterns. Since point measurements alone can never fully define the system, mathematical models and statistical methods must be used in conjunction with measurements to estimate overall leakage rates. Field work and modeling are supported with laboratory studies and geophysical data and measurements. Since fractures in cap rock and shallower formations may become migration pathways, our approach features development and use of the NETL explicit-fracture simulator NETLfLow for potential flow through both the fractures and matrix rock of consolidated sediments. Magnetometry and other survey techniques will be used to locate and evaluate abandoned or poorly sealed wells, which also constitute a significant leakage potential. Predictive models based on geophysical data and underground processes and accurate monitoring and validation protocols will greatly enhance public awareness of the effectiveness and benefits of large-scale sequestration approaches to reducing greenhouse gas emissions.

05: DE-FC26-04NT42262

Project Number: DE-FC26-04NT42262	***Project Title:*** Basic Science of Retention Issues, Risk Assessment & Measurement, Monitoring, & Verification for Geologic CO_2 Sequestration
Contacts DOE/NETL Project Mgr.	***Name*** Dawn Deel ***Organization*** National Energy Technology Laboratory ***E-Mail*** dawn.deel@netl.doe.gov
Principal Investigator	Lee H. Spangler, Montana State University
Partners	Rajesh Pawar, LANL; Pete McGrail, PNNL; Larry Myer, LBNL; Elizabeth Burton, LLNL; Grant Bromhal, NETL Subcontractor: Richard Bajura, West Virginia University
Stage of Development	X Basic R&D __ Applied R&D __ Proof of Concept __ Demonstration

Technical Background:

The existence of naturally occurring carbon dioxide (CO_2) reservoirs and experience with enhanced oil recovery operations are strong indicators that engineered subsurface storage of CO_2 can be safe and effective. However, large scale deployment will require greater confidence in understanding the fate of the CO_2 in the subsurface for both economic and safety reasons. The participating institutions in the Zero Emissions Research and Technology Collaborative (ZERT) have expertise in development of code to simulate multiphase flow through porous media and fracture networks, facilities and expertise for measurement of fundamental physical and chemical properties of systems under appropriate temperature and pressure conditions, and expertise in measurement, monitoring and verification. This project focuses on the basic science and development needs for improving the state of knowledge of CO_2 behavior in the subsurface by assessing knowledge gaps in fundamental physical and chemical properties in relevant systems, making measurements of those properties, improving numerical models by improving parameterization using these studies and by extending code capability, and testing efficacy and detection limits of measurement, monitoring and verification techniques. This information and the improved techniques can be incorporated into a systems level model for risk assessment also being developed in this project.

Relationship to NETL Carbon Sequestration Program:

This project is part of the Core R & D Program.

Primary Project Goal:

The primary project goal is to perform basic science and technology development to fill critical needs of the carbon sequestration program, specifically in the areas of measurement, monitoring and verification (MMV), improvement of computational techniques, risk assessment, mitigation, and fundamental geoscience studies of CO_2 properties and behavior.

Objectives:

The major objectives of the project are to:

1. Improve computational tools for simulation of CO_2 behavior in the subsurface. This includes adding reactive transport, development of coupled models to include geomechanics, inclusion of hysteretic effects, parallelization, etc.
2. Test efficacy of near-surface detection techniques, help establish detection limits for those techniques, and provide data to assist in development of transport models in the near-surface region. Develop a field site to help accomplish this objective.
3. Develop a comprehensive risk assessment framework that will allow flexible coupling of multiple computational models for different components/processes of the system.
4. Perform gap analysis to determine critical missing data for CO_2 properties in the subsurface including thermodynamic properties of CO_2 – brine mixtures, reaction rates, relative permeabilities, etc. In addition, perform laboratory based experiments to generate that key data.

06: DE-FC26-05NT42588

Project Number: DE-FC26-05NT42588	***Project Title:*** An Assessment of Geological Carbon Sequestration Options in the Illinois Basin		
Contacts DOE/NETL Project Mgr.	***Name*** John Litynski	***Organization*** NETL	***E-Mail*** john.litynski@netl.doe.gov
Co-Principal Investigators	Robert J. Finley Scott M. Frailey	Illinois State Geological Survey Illinois State Geological Survey	finley@isgs.uiuc.edu frailey@isgs.uiuc.edu
Partners	Indiana Geological Survey, Kentucky Geological Survey, Southern Illinois University, Brigham Young University, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Trimeric Corp., Silicon Prairie Sensors, Quantitative Geosciences (geostatistics), Bob Hardage (geophysics), Phil Caserotti (geophysics), Gary Crawford (well testing), James Lea (production and lift technology), Nyman & Associates (pipeline construction), George Asquith (well log analysis), Miller Technologies (EOR consulting), Steve Melzer (EOR consulting).		
Stage of Development	__Basic R&D	X_ Applied R&D	__ Proof of Concept X_ Demonstration

Technical Background:

The Midwest Geological Sequestration Consortium (MGSC) is investigating the options for geological carbon dioxide (CO_2) sequestration in the 60,000-mi2 Illinois Basin. Within the Basin, underlying most of Illinois, western Indiana, and western Kentucky, are deep and/or thin coal resources, numerous mature oil fields, and deep saline reservoirs potentially capable of storing CO_2. The objectives of the *Assessment* are to determine the technical and economic feasibility of using these geological sinks for long-term storage to avoid atmospheric release of CO_2 from fossil fuel combustion and thereby avoid the potential for adverse climate change.

The MGSC is a consortium of the geological surveys of Illinois, Indiana, and Kentucky, joined by subcontractors and consultants, to assess carbon capture, transportation, and storage processes, and their costs and viability, in the three-state Illinois Basin region. The Illinois State Geological Survey serves as the Lead Technical Contractor for the Consortium. The Illinois Basin region has annual emissions on the order of 302 million metric tons of CO_2 primarily from 122 coal-fired electric generation facilities, some of which burn almost 5 million tons of coal per year.

Initial work, termed Phase I during 2003-05, involved database development and assessment of carbon capture and transportation options in the region. All available data on potential carbon sinks and on applicable carbon capture approaches was compiled. Transportation options focused on both small-scale options for field tests and pipeline requirements for long-term sequestration. Research primarily focused on storage

reservoirs to assess each of the three geological sinks: coals, oil reservoirs, and saline reservoirs. Results were linked with integrated options for capture, transportation, and geological storage and the environmental and regulatory framework to define sequestration scenarios and potential outcomes for the region. A final task was to generate an action plan for possible technology validation field tests involving CO_2 injection, thus setting the stage for Phase II of the project and actual small-scale field tests during 2005-09. A 477-page final report, plus two topical reports on Phase I results, are available at www.sequestration.org, the MGSC web site.

A key outcome of Phase I was that the geology of the Illinois Basin is favorable for CO_2 sequestration. In some localities, two or more potential CO_2 sinks are vertically stacked. We are particularly focused, however, on the properties of the rock units that control injectability of CO_2, the total capacity for storage near major CO_2 sources, the safety of injection and storage processes, and the security of the overlying rock units that act as seals for the reservoirs. For Phase II (2005-09) a series of six small-scale field tests is underway. They include the testing of deep, and/or thin coal seams to adsorb gaseous CO_2, the ability to produce more oil from old fields by CO_2 flooding, and the injection of CO_2 into saline reservoirs some 5,000 to 9,000 ft below the surface. Each of our field tests will have an extensive monitoring program for sampling of air, shallow ground water, fluids from the injection zone, pressure changes, and geophysical and cased hole logging to understand the fate of injected CO_2 at our test sites. The integrity of the entire process will be scrutinized in detail to understand what contribution Illinois Basin geological sinks can make to national and international goals in accomplishing carbon sequestration and what technology developed here can be extrapolated to other regions.

Relationship to NETL Carbon Sequestration Program:

This project is part of NETL's Carbon Sequestration Program, Demonstration and Deployment element, and is one of seven Regional Carbon Sequestration Partnerships. As defined in the Office of Fossil Energy's Carbon Sequestration Technology Roadmap and Program Plan (2007), the partnerships are part of a program structure moving from Characterization (Phase I, completed) through Validation (Phase II, current work) to Deployment (Phase III, large-scale 1+ million ton tests, proposed).

Primary Project Goal:

The primary goal of this project is to assess and demonstrate the feasibility of geological carbon sequestration in coal seams, mature oil reservoirs, and saline reservoirs of the Illinois Basin, beginning with small-scale field tests, and moving toward a test of 1 million tons or more, in support of the commercial deployment of carbon sequestration.

Objectives:

During the current Phase II project, the Midwest Geological Sequestration Consortium (MGSC) is building on their Phase I assessment of the Illinois Basin for geological carbon dioxide (CO_2) sequestration by carrying out six small-scale CO_2 injection tests over a four-year period. MGSC to-date has evaluated coal beds, mature oil reservoirs, deep saline reservoirs, and, to a lesser extent, organic-rich shales as sinks for CO_2 storage. During Phase II, representative reservoirs are being selected from a portfolio of more than 30 potential test sites to carry out four types of validation tests: gas injection into coals, miscible and immiscible flooding of mature oil reservoirs, and a deep saline reservoir into which supercritical CO_2 will be injected. Careful assessment of each test site in advance of selection, environmental monitoring before, during, and after each test, and full documentation of results for each test are being carried out.

07: DE-FC26-05NT42592

Project Number: DE-FC26-05NT42592	***Project Title:*** Plains CO_2 Reduction (PCOR) Partnership - Phase II		
Contacts DOE/NETL Project Mgr.	***Name*** Darin Damiani	***Organization*** U.S. Department of Energy	***E-Mail*** Darin.Damiani@netl.doe.gov
Principal Investigator	Ed Steadman, Energy & Environmental Research Center, esteadman@undeerc.org		
Partners	68 Phase II partners		
Stage of Development	__ Basic R&D	__ Applied R&D	__ Proof of Concept X Demonstration

Technical Background:

The PCOR Partnership region covers an area of over 1.4 million square miles in the central interior of North America, including nine states and four Canadian provinces. The PCOR Partnership region is an ideal location for demonstrating carbon capture and sequestration (CCS) because many large sources in the region are proximally located to large-capacity sinks, and in some cases, the infrastructure necessary for CO_2 sequestration is partially in place. CO_2-based enhanced hydrocarbon recovery projects represent value-added sequestration technologies that have the potential for future large-scale deployment in the region if pilot projects demonstrate technical and economic feasibility. Three geologic projects and one terrestrial sequestration project were selected for demonstration in the PCOR Partnership region during Phase II.

Relationship to NETL Carbon Sequestration Program:

The PCOR Partnership is focused on field testing and demonstration of technologies that take CO_2 from large stationary sources and sequester it using geologic and terrestrial approaches. Widespread deployment of carbon sequestration also requires the development and demonstration of practical methods for public outreach; regulatory oversight; CO_2 capture and storage; and measurement, monitoring, and verification (MMV) technologies at or near commercial scale.

Primary Project Goal:

The overall goal of the proposed work of Phase II of the PCOR Partnership is to validate the most promising sequestration technologies and infrastructure concepts identified in Phase I activities through field validation tests, to continue outreach activities, to refine the regional characterization efforts started in Phase I, and to develop Phase III demonstration opportunities.

Objectives:

The objectives of the proposed work are to develop solutions for the capture, transport, and storage of anthropogenic greenhouse gas (GHG) emissions in the PCOR Partnership region. These solutions will be transferable to other regions of the country and will fill existing data gaps with respect to sink capacity and permanence, economics, risk, public acceptance, and societal co-benefits. These objectives will be achieved by 1) continued systematic filling of data gaps regarding the utility and capacity of regional CO_2 sinks, 2) implementation of field validation tests that adequately validate the feasibility of regionally and nationally significant sequestration technologies and infrastructural concepts, 3) transfer of the results to the U.S. Department of Energy (DOE) as well as other public and private sector stakeholders dealing with carbon sequestration issues, and 4) implementation of outreach programs that inform the public about carbon sequestration and engage the public as stakeholders in conducting the projects.

08: DE-FC26-05NT42592

Project Number: DE-FC26-05NT42592	***Project Title:*** West Coast Regional Carbon Sequestration Partnership (WESTCARB)		
Contacts DOE/NETL Project Mgr.	***Name*** Dawn Deel	***Organization*** NETL	***E-Mail*** Dawn.Deel@NETL.doe.gov
Principal Investigator	Larry Myer	Lawrence Berkeley National Lab	LRMyer@lbl.gov
Partners	Rosetta Resources, Salt River Project, EPRI, Schlumberger, and Praxair work most closely with LBNL; there are more than 70 organizations participating in the overall project		
Stage of Development	__ Basic R&D	X Applied R&D	__ Proof of Concept __ Demonstration

Technical Background:

Geologic sequestration is one of a portfolio of approaches for mitigation of climate change caused by increasing levels of carbon dioxide in the atmosphere. The technology approach involves capture of CO_2 at large point sources, transport by pipeline and injection into the deep subsurface, where the primary injection targets are porous saline formations in sedimentary basins, and the oil and gas reservoirs, and coal formations also found in these basins. A large technology base already exists for application to geologic sequestration; challenges remain in assessing and defining regional opportunities. For the subsurface component, evaluation of capacity, leakage risks, and mitigation of leakage risk are key technical issues. Field pilots provide essential information to address these issues.

Relationship to NETL Carbon Sequestration Program:

The West Coast Regional Carbon Sequestration Partnership (WESTCARB) is one of seven Regional Partnerships established to assess carbon dioxide sequestration opportunities across the United States. Phase I of the Partnership program involved regional assessments of sequestration opportunities. Phase II continues regional assessments while focusing on small scale field pilots. LBNL had/has responsibility for specific tasks as discussed below.

Primary Project Goal:

The objective of the overall WESTCARB project is to assess and define sequestration opportunities in the WESTCARB region and develop information and experience to enable commercialization of sequestration technologies. In Phase I, which is complete, LBNL contributed to this goal by leading the assessment of geologic storage capacity in the West Coast states, and by assessing leakage risks and monitoring technologies. In Phase II, LBNL's primary goal is to provide essential pre-deployment information and experience through completion of two geologic pilot tests.

Objectives:

In Phase I of WESTCARB, which is complete, LBNL's objectives were:

1. Develop geologic data to characterize the geologic sequestration potential and storage capacity of the west coast states;
2. Develop a method/tool to compare, rank, and select sites for sequestration, including leakage risk factors; and
3. Assess monitoring technology options with specific focus on West Coast applications.

In Phase II, LBNL's work focuses on carrying out two geologic sequestration pilots, one in the Central Valley of California, and one in northeastern Arizona. These pilots are representative of the best sequestration options in the Region, and provide site-specific information on capacity, costs, leakage risks, public acceptance, regulatory requirements, and monitoring methods. The specific technical objectives of the California pilot, which involves injection into a saline formation and a depleted gas reservoir, are:

1. Assess seal integrity,
2. Assess the spatial extent of the CO_2 plume,
3. Determine the storage capacity of the reservoir,
4. Determine injectivity of the reservoir,
5. Evaluate potential environmental impacts, and
6. Study processes influencing enhanced gas recovery using CO_2.

The objectives of the Arizona pilot are similar, except that it involves injection only into a saline formation.

09: DE-FC26-05NT42587

Project Number: DE-FC26-05NT42587	***Project Title:*** Big Sky Carbon Sequestration Partnership - Phase II		
Contacts DOE/NETL Project Mgr.	***Name*** David Lang	***Organization*** DOE/NETL	***E-Mail*** David.Lang@NETL.doe.gov
Principal Investigator	Dr. Lee Spangler	Montana State University	spangler@montana.edu
Partners	University of Idaho, University of Wyoming, Washington State University, South Dakota School of Mines and Technology, Oregon State University, Columbia University, Battelle, Los Alamos National Laboratory, Idaho National Laboratory, National Offset Coalition, The Sampson Group, Entech Strategies		
Stage of Development	__ Basic R&D	__ Applied R&D	__ Proof of Concept X Demonstration

Technical Background:

The Big Sky Carbon Sequestration Partnership (BSCSP) relies on existing technologies from the fields of engineering, geology, chemistry, geographic information systems and economics to develop novel approaches for carbon storage in our region. Our efforts focus on improving the understanding of factors affecting CO_2 storage permanence, capacity, and safety in geological and terrestrial ecosystems. The BSCSP research also analyzes the policy and regulatory frameworks, economics and infrastructure needs to deploy the developing technologies at a commercial scale. The BSCSP is distinct for its comprehensive research projects in terrestrial sequestration, geologic sequestration in mafic rocks and describing the economic criteria for successful implementation of Carbon Capture Storage (CCS). In particular, BSCSP is actively developing econometric models that simulate the cost of deployment of a wide range of sequestration approaches over a range of carbon prices to develop supply curves that address DOE cost goals.

Relationship to NETL Carbon Sequestration Program:

The Big Sky Carbon Sequestration Partnership is one of seven of NETL's regional carbon sequestration partnerships. The partnerships engage state agencies, universities, energy producers, and key stakeholders to create a nationwide network that will help determine the best approaches for capturing and permanently storing greenhouse gases. Work accomplished through regional carbon sequestration partnerships helps determine the most suitable technologies, regulatory and policy frameworks, and infrastructure needs for carbon capture, storage, and sequestration.

Primary Project Goal:

The primary goal of the Big Sky Carbon Sequestration Partnership is to promote the development of a regional framework and infrastructure required to validate and deploy carbon sequestration technologies.

Objectives:

The BSCSP has specific measureable objectives for each component of the project. These objectives ensure success in meeting the overall Primary Project Goal.

The *geologic* objectives are to develop detailed characterization information of the subsurface geological features; model and simulate subsurface CO_2, water and rock behavior; and conduct pilot projects to assess the viability, technical feasibility, capacity, and risks associated with large-scale geologic sequestration. The characterization efforts examine faults, fractures, aquifer salinity, rock type, permeability, porosity, thickness and a real extent through acquisition and analysis of new data. Field measurements are analyzed for history matching of simulated and observed data and for refining capacity estimates. The characterization and modeling work will provide a foundation to evaluate measurement, monitoring, and verification (MMV) performance on a commercial scale and to address critical technical and risk avoidance issues associated with CO_2 injection.

The *terrestrial* objectives are to quantify and determine cropland, rangeland and forestry management practices that optimize soil carbon sequestration; to develop MMV protocols to successfully evaluate carbon sequestration while reducing verification costs; and to support the creation of a viable carbon market.

The *economic* objectives are to assess the economic feasibility of regional geologic and terrestrial sequestration and to develop models that evaluate CO_2 sequestration potential, land use and management, implementation costs, policy and regulatory needs, carbon markets, and risk and uncertainty.

The *outreach* objectives are to provide information and keep the public informed of the partnership's pilot projects; facilitate communication and collaboration; and provide educational training for students.

The *regulatory compliance* objectives are to develop regulatory guidelines to govern the implementation of carbon capture and sequestration and ensure that all permitting requirements are met.

10: DE-FC26-05NT42430

Project Number: DE-FC26-05NT42430	***Project Title:*** Oxygen-Fired CO_2 Recycle for Application to Direct CO_2 Capture from Coal-Fired Power Plants
Contacts DOE/NETL Project Mgr.	***Name*** Timothy Fout ***Organization*** National Energy Technology Laboratory ***E-Mail*** Timothy.Fout@netl.doe.gov
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Stage of Development	__ Basic R&D __ Applied R&D X Proof of Concept __ Demonstration

Technical Background:

Oxy-enhanced combustion has been pursued for a number of years by industries and oxygen suppliers for the purpose of increasing process production, energy efficiency, and reducing NO_X emissions. Recently, experimental and computational research experience with oxygen-fired CO_2 recycle has been obtained, along with research in related areas, such as chemical looping. Notable experience has been obtained previously in the area of oxygen-fired CO_2 recycle in a variety of different laboratory and bench-scale units, including an ~8-MMBtu/hr pilot test at Jupiter Oxygen Corporation, firing sub-bituminous coal and ALSTOM Power's 10 MW demonstration unit. Although there is a significant amount of data available, additional data is needed to aid in developing a relationship between the adjustable parameters for oxy-fired CO_2-recycle and NO_X emissions, unburned carbon in the ash, efficiency improvements, flame stability, heat flux, boiler temperatures, and to provide a better quantitative prediction of capital and operating economics.

MAXON Corporation, a major participant in the proposed work, has previously designed both oxy-fired natural gas and oxy-fired coal burners for an oxy-fired CO_2 recycle test in the Jupiter Oxygen Corporation ~8 MMBtu pilot-plant. Proof-of-concept tests at the Jupiter pilot-plant showed significant decreases in NO_X emissions for both staged and unstaged firing conditions, while firing a sub-bituminous coal. In addition, numerous laboratory and bench-scale tests have also shown that oxy-enhanced combustion can be used to reduce NO_X formation.

A full-scale retrofit of a Turbo Oxy Cycle power plant has been performed, resulting in 98% purity of CO_2 in the flue gas. This significant achievement was performed without any change of the pressure parts of the boiler. In doing so, the furnace outlet temperature, radiation characteristics of the furnace, and heat duties of the boiler were maintained.

Southern Research Institute has teamed with REI and other partners before on similar projects, and they were highly successful. In the case of a previous biomass/coal-co-firing project, a detailed understanding of the relationship between NO_X emissions and biomass/coal co-firing was obtained for a wide range of operating conditions. Parameters examined included various means of co-firing the biomass (blended, co-milled, separate injection (in-flame and post flame)), staging the air (including use of low-NO_X burners), different coal types (from anthracite to sub-bituminous), and altering burner swirl and furnace exit oxygen. In the previous project, a complete map of NO_X emissions and char burnout was created that traversed the broad range of coal types and firing conditions that exist across the fleet of coal-fired boilers in North America.

Relationship to NETL Carbon Sequestration Program:

This project fits into the CO_2 CAPTURE area of the NETL Carbon Sequestration Program, as a means to major cost reductions in reducing or eliminating carbon dioxide emissions from energy plants. The first step towards reducing the cost of CO_2 capture is to reduce the volume of flue gas to be treated and produce a concentrated stream of CO_2 that can be directly mitigated without interference from dilution gases. Oxy-fired CO_2 recycle has the potential to reduce the volume of flue gas by 75% on a wet basis. This reduction in flue gas volume is accomplished primarily by eliminating the large volume of nitrogen, an inert gas, from the flue gas associated with air-blown combustion. Condensing the water out of the CO_2-enriched flue gas can reduce the volume of the flue gas further, and produce a relatively high-purity stream of CO_2 that can be operated on directly by a variety of sequestering technologies. By replacing the nitrogen in the air with recycled CO_2, the flame can be maintained near typical air-blown flame temperatures, and existing boilers, materials, feed systems, water walls, steam tubes, steam cycles, and existing ancillary equipment may be used for retrofit applications.

Primary Project Goal:

The primary goal of this project is to obtain the additional information necessary in this proof-of-concept-focused study (through experimental work, CFD modeling, and economic analysis) to enable our utility and product-development partners to move on with us to a full-scale demonstration of Oxy-Fired CO_2 Recycle, as a retrofit on an existing coal-fired electric utility power plant.

Objectives:

The objective of this project is to thoroughly investigate, develop, optimize, and model oxygen-fired CO_2 recycle for retrofit application to coal-fired utility boilers. Oxygen-fired CO_2-recycle combustion will be extensively investigated in the semi-industrial-scale Combustion Research Facility, at Southern Research Institute, to develop a complete fundamental understanding of the effects of retrofitting this technology to existing air-blown coal-fired boilers, with a minimum capital expenditure. Specifically, it is intended that existing boilers, materials, and coal-feeding systems will be used.

The mechanisms elucidated in the oxy-enhanced combustion investigation will be used to validate a model that will completely describe temperatures, reaction rates, devolatilization, char burnout, and NO_X formation and/or destruction, as a function of oxygen purity, stoichiometry, coal type, staging, furnace exit oxygen, and fuel processing. The effects of retrofitting this technology on heat transfer in the furnace and convective sections will also be examined, as well as the effects on fouling and slagging.

Of great importance, the research team will continue to work with the utility partners on this project as it proceeds to identify and answer the questions that need to be addressed in order to perform a full-scale demonstration on one of their existing full-scale power plants.

11: DE-FC26-06NT42748

Project Number: DE-FC26-06NT42748	***Project Title:*** Pilot-Scale Demonstration of a Novel, Low-Cost Oxygen Supply Process and its Integration with Oxy-Fuel Coal-Fired Boilers		
Contacts DOE/NETL Project Mgr.	***Name*** Timothy Fout	***Organization*** National Energy Technology Laboratory	***E-Mail*** Timothy.Fout@netl.doe.gov
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Stage of Development	__ Basic R&D	__ Applied R&D	X Proof of Concept __ Demonstration

Technical Background:

This project concerns the pilot-scale demonstration of a novel high-temperature sorption-based technology referred to as CAR (Ceramic Autothermal Recovery) for oxygen production and supply to oxyfuel boilers with flue gas recycle. The process utilizes the oxygen storage capacity of perovskite materials at high temperatures, and involves cyclic operation with traditional fixed bed vessels containing material in the form of extrudates. In the first step, air is passed through a bed at approximately 800ºC to allow the oxygen to be stored. In a second step, a sweep gas such as flue-gas or low pressure steam or a combined stream is passed through the bed to release the stored oxygen and the resultant oxygen-carbon dioxide mixture is used in the coal-fired plant. Additional rinse steps are added to remove nitrogen present in the voids at the end of the air step as well as CO_2 present in the voids at the end of the sweep gas step. An important feature of the CAR process, which makes it ideally suited for oxy-combustion with the flue gas recycle, is that it can be tailored to produce low-pressure oxygen at the concentration required for combustion by using recycled flue gas as sweep gas. The use of the flue gas requires that the potential contaminants (particulates, SO_X, NO_X and other trace elements) should be separated to an acceptable level if they affect the perovskite material performance.

Relationship to NETL Carbon Sequestration Program:

This project falls under the "Carbon Capture Plant" initiatives of the NETL Carbon Sequestration Program. It supports the CCS goals by proving an option for reducing the cost of capture by providing an alternative technology for oxygen supply to the oxy-combustion process.

Primary Project Goal:

Conduct pilot-scale testing of BOC's CAR oxygen generation process, when integrated with a coal-fired combustor to produce a CO_2-rich flue gas and demonstrate process validation and benefits compared to oxygen supply from a cryogenic air separation process for application in retrofitting existing power plants for oxy-combustion.

Objectives:

Phase 1 Objectives (18-months, 1st Budget Period):

- Evaluate the performance of a 0.7 tons/day O_2 pilot-scale CAR system, when fully integrated with a pilot-scale coal combustor and determine the optimum operating conditions of this unit.
- Perform a techno-economic evaluation of a commercial-scale oxygen-fired power plant that utilizes a CAR system to provide the oxygen.
- Perform long-duration tests on the CAR unit to determine long-term effects of the CAR bed materials.

Phase 2 Objectives (18-months, 2nd Budget Period):

- Design and construct a 10 ton/day O_2 pilot-scale CAR unit.
- Evaluate the performance of the pilot-scale CAR unit when integrated with both a pulverized coal-fired and a CFB combustor.
- Refine the techno-economic study and develop a detailed commercialization plan.

12: DE-FC26-06NT42808

Project Number: DE-FC26-06NT42808	***Project Title:*** Utah Center for Ultra Clean Coal Utilization		
Contacts DOE/NETL Project Mgr.	***Name*** David Lang	***Organization*** NETL	***E-Mail*** lang@netl.doe.gov
Principal Investigator	Ronald J. Pugmire Adel F. Sarofim	University of Utah University of Utah	pug@vpres.adm.utah.edu sarofim@aros.net
Partners	Reaction Engineering International Brigham Young University		
Stage of Development	X Basic R&D	__ Applied R&D	__ Proof of Concept __ Demonstration

Technical Background:

The Utah Clean Coal Center's mission is the generation of scientific and technical information to allow for the clean and efficient utilization of coal in a carbon-constrained world. Building on the existing core-competencies developed over a long history of basic and applied research in coal science and combustion processes, the Utah Clean Coal Center will support DOE's goals in the following five thrust areas: simulation, mercury control, oxy-fuel combustion, gasification, and sequestration.

Relationship to NETL Carbon Sequestration Program:

Sequestration is one of the Utah Clean Coal Center's Thrust Areas. Results from The Clean Coal Center may lead to Advanced (Breakthrough) technologies. The Sequestration Thrust Area will help understand geologic storage integrity and measurement, monitoring and verification.

Primary Project Goal:

The primary objective of the Sequestration Thrust Area is to study the impact of contaminant gases on sequestration chemistry and vertical mixing of CO_2 and brine.

Objectives:

The Sequestration Thrust Area has two main objectives: studying the impact of contaminant gases on sequestration chemistry and studying vertical mixing.

The impact of contaminant gases on sequestration chemistry will be studied by measuring reaction rates for CO_2, brine, and rocks in a newly designed high-temperature, high pressure experimental assembly. The Clean Coal Technology, with a variety of process pathways, results in a CO_2 stream that could contain a host of other constituents, such as water, hydrogen sulfide, sulfur oxides, nitrogen oxides, ammonia, etc. Specifications of the compositions of the gas to be sequestered are oftentimes based on pipeline requirements or guidelines of enhanced oil recovery process where CO_2 injection is employed. The experiments performed under the following subtasks will help develop an understanding of the reactivity of these mixtures.

The ultimate fate of CO_2 in a sequestration environment depends on the distribution of CO_2 and brine in the aquifer along with the reactivity. Simulations have shown that due to the density difference between carbonated brine (denser and at the top) and brine (lighter and at the bottom) gravity-driven plumes of CO_2-laden water result, enhancing the mixing process in the formation. There is some uncertainty in the development and progression of these plumes, which significantly impacts the overall time of equilibration in an aquifer. Vertical mixing and equilibration times will be evaluated using two different commercial simulators for subsurface injection and transport.

13: DE-FC26-06NT42811

Project Number: DE-FC26-06NT42811	***Project Title:*** Jupiter Oxycombustion and Integrated Pollutant Removal for the Existing Coal Fired Power Generation Fleet		
Contacts DOE/NETL Project Mgr.	***Name*** Bruce Lani	***Organization*** National Energy Technology Laboratory	***E-Mail*** Bruce.Lani@netl.doe.gov
Principal Investigator	Mark Schoenfield, Jupiter Oxygen Corporation M_Schoenfield@jupiteroxygen.com		
Partners	Paul Turner, National Energy Technology Laboratory Paul.Turner@NETL.DOE.GOV William Simmons, CoalTeck LLC, wsimmons@coalteck.com		
Stage of Development	__ Basic R&D	X Applied R&D	__ Proof of Concept __ Demonstration

Technical Background:

The underlying technology concept for this project is the use of a unique and efficient oxy-fuel combustion process, used in aluminum melting for over a decade, and combining it with a pollutant removal system that also recovers heat back to the boiler and captures CO_2.

To summarize the salient features of Jupiter's process: use of oxygen instead of air, high flame temperature ("undiluted" – not cooling with recirculation or nitrogen), increased radiant heat transfer, reducing fuel input to match current thermal requirements, flame shaping, staged low NO_X specially designed oxygen burners (ultra low NO_X without additional equipment), near stoichiometric combustion (low excess oxygen) with proper mixing of oxygen and fuel, and use of standard oxygen combustion burner materials such as high temperature refractory tip rather than lower temperature air combustion materials such as steel.

The Integrated Pollutant Removal (IPR) system, as developed by NETL, separates condensable vapors from combustion in the non-condensable gases (such as Ar, O_2 and N_2) in coal combustion using a series of direct and indirect heat exchangers and compression steps, while recovering useful heat. In the process, pollutants are removed with the condensate streams and/or kept in the CO_2. The NETL IPR technology is most effective when conditioning a concentrated (without significant N_2 or excess oxygen) flue gas stream. This makes Jupiter's oxy-fuel combustion and IPR technology complementary.

Previous sequestration related work, by Jupiter Oxygen with the NETL, showed that this combination of technologies could effectively capture CO_2 from the combustion of coal. Combustion gas tests, in a 75 KWh unit, showed NO_X levels at 0.088 pounds per million British thermal units (lb/106 Btu), without any back end NO_X removal equipment. With the addition of the Integrated Pollutant Removal system, more than 80% of the CO_2 was captured at pressures which showed greater then 95% capture is feasible, while 99+% of the SO_X and particulates were captured. Particle-bound mercury was removed from the flue gas, and mercury vapor

was concentrated at the end of the process, where proven technologies were used to collect approximately 90% of the mercury.

This project relates to performance goals of the DOE Sequestration roadmap for greater than 90% CO_2 capture from the flue gas with projected costs close to the current cost of electricity (consistent with the 2012 goal of not more than a 10% increase for capture, transport and sequestration). In addition, the product of work (burners) from this project is needed for a planned 25 MWe power plant retrofit that can be completed before DOE's goal of a pilot boiler project in 2012.

Relationship to NETL Carbon Sequestration Program:

The Carbon Sequestration Program identifies oxy-combustion as a research pathway / technology area for capture.

Primary Project Goal:

The primary project goal is the development of scaled up oxy-fuel burners, and further process refinement of Integrated Pollutant Removal for an actual retrofit of a 25 MWe power plant on the grid.

Objectives:

The purpose of this project is (1) the development of oxy-fuel burners which are consistent with the Jupiter Oxygen oxy-fuel process, (2) the capture of CO_2 using the Jupiter Oxygen combustion process with the Integrated Pollutant Removal (IPR) technology developed by the National Energy Technology Laboratory, (3) the combination of the technologies to meet DOE sequestration program requirements for cost of electricity and (4) data collection on material performance in an oxy-fuel combustion environment.

This project will include the design, procurement, construction, installation and operation of a 15MWth (scale per actual burner needed for planned 25 MWe retrofit) burner test facility with a 50 kW (slip stream) IPR unit in Hammond, Indiana. The preliminary test plan is being reviewed by NETL to finalize test matrices. Final NETL test plan approval will be completed prior to steady state testing operational.

One milestone is a 15 MWth, low NO_X oxy-fuel burner capable of retrofit application. A second milestone is operation of the slip stream IPR system consistent with retrofit application. Testing is to be done with Ohio bituminous coal utilized by Orrville Utilities (planned retrofit site) in both parametric studies and at least one case study at steady state conditions for three weeks of continuous twenty-four hour per day operation.

Concurrently, the NETL's Office of Systems Analyses and Planning, with Jupiter Oxygen, will generate necessary information (equipment requirements and performance) required as inputs into a systems analysis of Jupiter oxy-fuel and IPR technological viability for economic scale-up, either in combination or individually with generic counterparts, and conformance to DOE's Sequestration Program Goals.

14: DE-FG26-04NT42122

Project Number: DE-FG26-04NT42122	***Project Title:*** Design and Evaluation of Ionic Liquids as Novel CO_2 Absorbents		
Contacts DOE/NETL Project Mgr.	***Name*** Jose Figueroa	***Organization*** DOE NETL	***E-Mail*** jose.figueroa@netl.doe.gov
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Partners	Joan Brennecke	Univ. of Notre Dame	jfb@nd.edu
Stage of Development	X Basic R&D	__ Applied R&D	__ Proof of Concept __ Demonstration

Technical Background:

Ionic liquids are salts that in their pure state are liquid near ambient conditions. They have been shown to have no vapor pressure and high thermal stability. We showed that they also have relatively high CO_2 solubility and low N_2 solubility, which suggests they may be effective for absorption-based CO_2 capture. There are an almost infinite number of compounds that can be made into an ionic liquid. This is an exploratory project to see if new ionic liquids can be synthesized that have properties which will make them cost effective for CO_2 capture. The key properties include high CO_2 solubility and selectivity, high thermal stability and low heat of regeneration. To design new ionic liquids with desirable properties, a combination of molecular modeling and targeted experimental synthesis and property measurement has been used. Ionic liquids are different from conventional absorbents because their non-volatile nature makes them easy to regenerate. Their solubility and regeneration energy can be tuned through addition of substituent groups.

Relationship to NETL Carbon Sequestration Program:

This project is listed under the "Breakthrough Concepts" category. Prior to this project, there were no research efforts on the use of ionic liquids for CO_2 capture.

Primary Project Goal:

To discover an ionic liquid sorbent that has CO_2 solubility and selectivity that approaches that of traditional amine-based absorbents but that requires a fraction of the energy to regenerate, therefore resulting in economic capture of >90% of CO_2 from flue gas.

Objectives:

- Carry out theoretical calculations to understand mechanism of CO_2 solubility in ionic liquids
- Identify first generation ionic liquids to synthesize
- Synthesize, purify, and characterize first generation ionic liquids for testing
- Carry out physical property screening measurements of first generation ionic liquids
- Conduct analysis of operational and economic feasibility to set property targets
- Carry out synthesis, purification and characterization of second generation ionic liquids
- Perform theoretical modeling of gas absorption in ionic liquids
- Measure pure and mixed gas solubility in strong candidate compounds
- Measure liquid-liquid equilibria for candidate compounds
- Carry out heat capacity, thermal decomposition and viscosity measurements
- Write final report, and assess path forward

15: DE-FC26-07NT43091

Project Number: DE-FC26-07NT43091	***Project Title:*** Ionic Liquids: Breakthrough Absorption Technology for Post-Combustion CO_2 Capture		
Contacts DOE/NETL Project Mgr.	***Name*** David Lang	***Organization*** DOE NETL	***E-Mail*** David.Lang@netl.doe.gov
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Stage of Development	X Basic R&D	__ Applied R&D	__ Proof of Concept __ Demonstration

Technical Background:

Ionic liquids are salts that in their pure state are liquid near ambient temperatures. They have essentially no vapor pressure, are thermally stable, have high solubility for CO_2 but low solubility for N_2. Previously, we showed that both CO_2 and SO2 are highly soluble in certain ionic liquids. We demonstrated that the dissolution mechanism for the systems examined is purely physical. The enthalpy of absorption (and hence regeneration energy) is therefore low. A preliminary economic analysis suggested that higher CO_2 capacities are needed to make ionic liquids economically viable for post-combustion CO_2 capture. Many different compounds can be made into an ionic liquid, but we don't understand how chemical structure controls properties. Work needs to be done in which new ionic liquids are designed specifically for CO_2 capture. Also, novel process designs need to be developed and tested that can exploit some of the unique properties of ionic liquids.

Relationship to NETL Carbon Sequestration Program:

This project is a follow on to the "Breakthrough Concepts" project DEFG26-04NT42122 and is focused on developing new technologies for CO_2 capture.

Primary Project Goal:

To discover an ionic liquid that can be used in either a conventional absorber or a novel process configuration which can be used to capture > 90% CO_2 from flue gas in a more economically attractive manner than competing technologies.

Objectives:

1. Design and synthesize one or more ionic liquid absorbents having physical properties tailored for post-combustion CO_2 capture.
2. Perform atomistic-level classical and quantum calculations to engineer ionic liquid structures that maximize CO_2 carrying capacity while minimizing regeneration costs.
3. Measure or accurately estimate all physical properties of the absorbent that are essential for detailed engineering and design calculations.
4. Complete a detailed systems and economic analysis study in accordance with NETL's Carbon Capture and Sequestration Systems Analysis guidelines.
5. Demonstrate the CO_2 capture technology with a continuous lab-scale unit.
6. Develop a path forward for commercialization.

16:T401.01.01

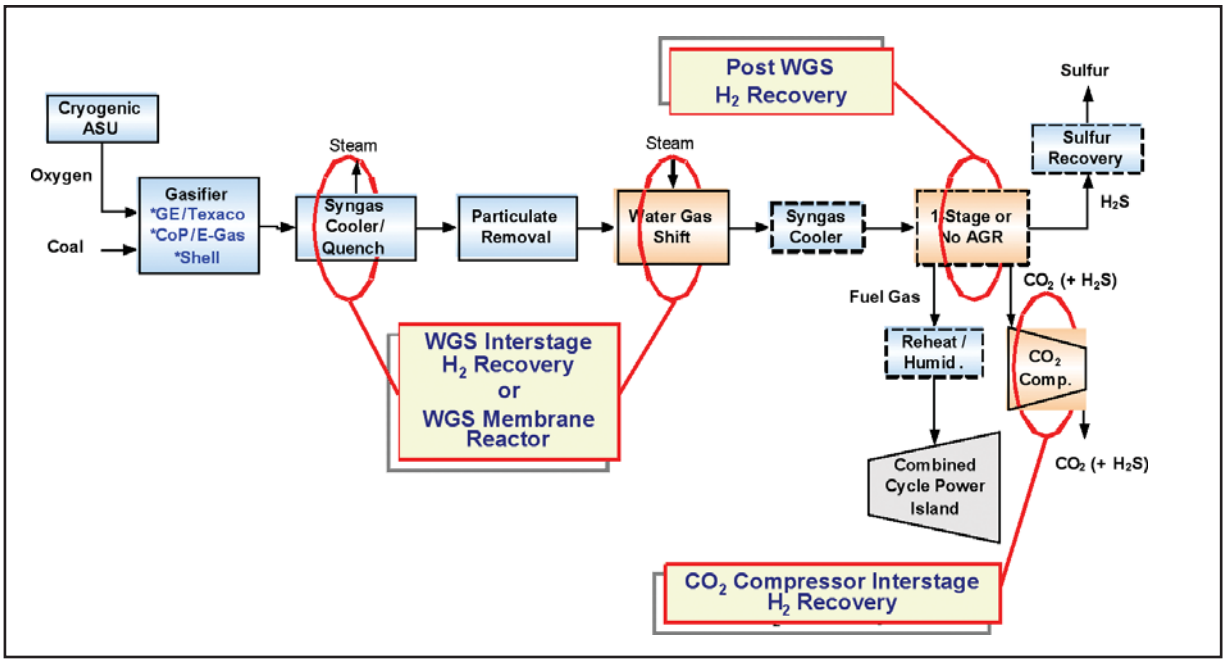
Project Number: T401.01.01	***Project Title:*** Membrane Selection and Placement for Optimal CO_2 Capture from IGCC Power Plants		
Contacts DOE/NETL Project Mgr.	***Name*** Jared P. Ciferno	***Organization*** NETL/OSAP	***E-Mail*** jared.ciferno@netl.doe.gov
Principal Investigator	Jared P. Ciferno	NETL/OSAP	jared.ciferno@netl.doe.gov
Partners			
Stage of Development	__ Basic R&D __ Applied R&D __ Proof of Concept __ Demonstration X Systems Analysis		

Technical Background:

Fossil Energy RD&D is currently investigating technologies for the capture and sequestration of carbon dioxide emitted by power plants. The goal of this program is to develop technologies which can capture 90% of the CO_2 produced, with less than a 10% increase in the cost of electricity. A system analysis of advanced hydrogen-separation membrane technologies is in progress. This assessment will establish which process design and membrane performance factors are critical for successful development of membrane technologies for Integrated Gasification Combined Cycle (IGCC) power plant applications. A number of membrane configurations are being evaluated and compared to a state-of-the-art IGCC power plant retrofitted with existing commercial CO_2 capture technology. This analysis will allow cost and performance targets to be established to help DOE project managers and technology developers as they work to improve membrane permeance and selectivity, and lower the cost of membrane separation systems.

Figure 1 identifies possible integrations of gas separation membranes into an advanced IGCC power plant. Process conditions, gas composition, pressure and temperature, are different at the various locations identified in this figure. The operating envelope for any given membrane technology must match the conditions where it will be located in the process. Each location has its own unique advantages and disadvantages in regards to hydrogen separation and recovery. In addition, other technologies under development, such as warm-gas clean-up systems, may impact selection of a H_2/CO_2 separation technology, and may or may not complement membrane separation. Proper placement of a membrane unit in the process flowsheet is critical, and it is unlikely that one type of membrane material can perform adequately in all feasible locations in the process. Therefore, the challenge is to take advantage of the unique characteristics of individual membrane technologies, while mitigating any shortcomings.

FIGURE 1 INTEGRATION OF MEMBRANE-BASED GAS SEPARATIONS WITH IGCC



Relationship to NETL Advanced Power Systems Program:

This analysis is relevant to several advanced coal gasification technologies for producing power and/or hydrogen, including CO_2 capture, H_2 production and purification, and syngas clean-up. The targets developed in this analysis will be used to review the performance and R&D progress of a number of membranes being developed with DOE sponsorship, including: the LANL high-temperature polymer membrane, NETL PD/Cu membranes, and the membranes being developed by Eltron. The models have already been used to evaluate the performance and set targets for the nanoporous membranes under development at ORNL.

Primary Project Goal:

This analysis will establish membrane cost and selectivity targets that can be used to measure the progress of existing DOE R&D efforts and to screen future DOE-funded membrane R&D projects. It will also identify issues related to the use of membranes for H_2/CO_2 separations and to the integration of these membranes with other advanced technologies, such as warm-gas clean-up.

Objectives:

1. Model Development:

a) Develop a simple model for predicting ideal membrane separator performance to be used as a tool to quickly screen possible membrane configurations

b) Develop a rigorous model of a membrane separator to be used to predict membrane performance and area requirements

c) Develop Aspen simulation models for a baseline IGCC plant based on Selexol CO_2 removal process, and for the various membrane configurations to be studied in this analysis

d) Develop economic spreadsheet calculate levelized COE for various cases developed

2. Analysis:

a) Screen membrane configuration options

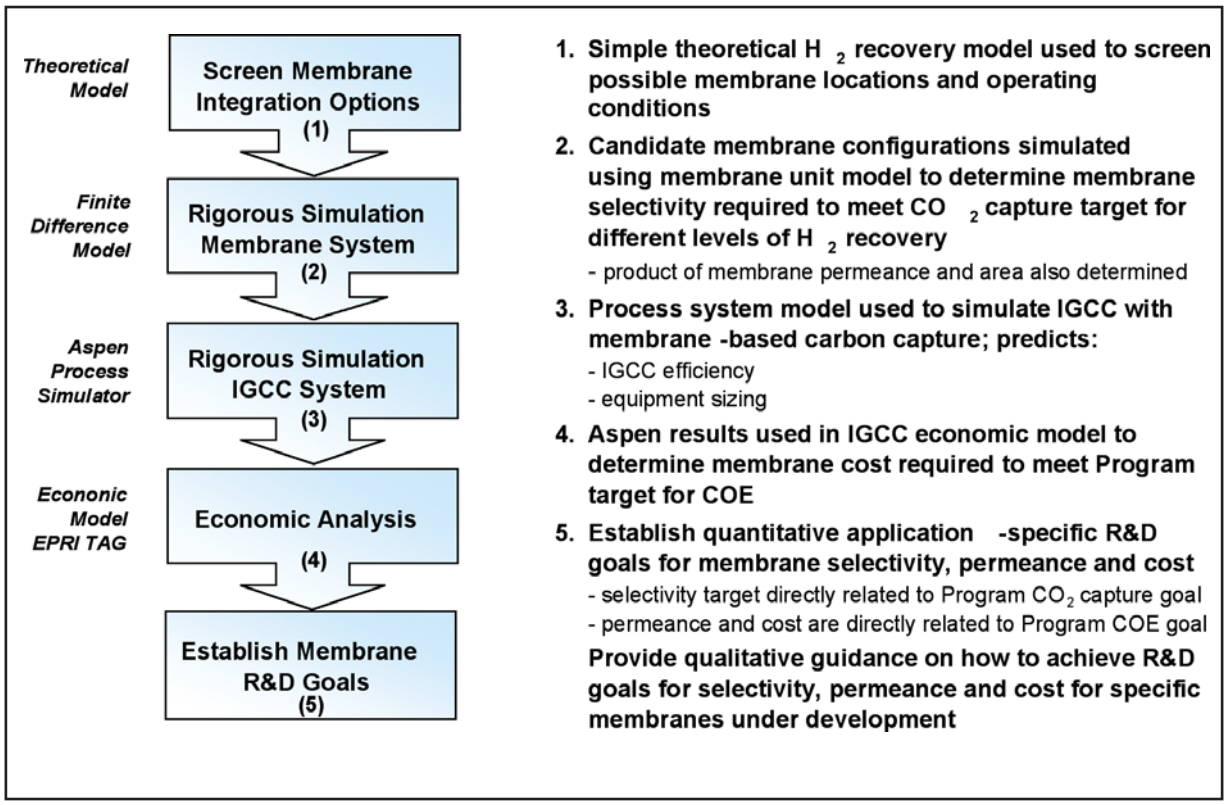
b) Perform rigorous simulation of membrane system

c) Perform rigorous simulation of IGCC system

d) Perform Economic Analysis

3. Establish Membrane R&D Goals.

The methodology used by NETL to integrate gas separation membranes into the IGCC process is shown below:



17: ORD-07-220614

Project Number: ORD-07-220614	***Project Title:*** Ionic Liquid-Based Membranes for CO_2 Separations in Fuel Gas Applications		
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Stage of Development	X Basic R&D	__ Applied R&D	__ Proof of Concept __ Demonstration

Technical Background:

Coal gasification technologies, such as the integrated gasification combined cycle (IGCC), will constitute a significant portion of future energy production. A key challenge in the development of these technologies as "zero emission" power sources is the design of efficient techniques which allow the capture of CO_2 from the fuel gas. The greatest CO_2 capture efficiency in IGCC systems is achieved by separating concurrently with the equilibrium limited water-gas shift reaction. In this way, the reaction may be driven to completion at a higher temperature resulting in richer, reduced-carbon fuel gas. Ionic liquid based facilitated transport membranes have the potential to selectively separate CO_2 under the very demanding conditions present in the water-gas shift reactor (>260ºC, 40 atm).

Relationship to NETL Carbon Sequestration Program:

The project falls within the Pre-Combustion Capture portion of the CO_2 Capture core research area.

Primary Project Goal:

The project goal is to develop an ionic liquid-based, CO_2 selective membrane capable of operating at the conditions of the low temperature water-gas shift reactor for use in the IGCC process.

Objectives:

Early work on the project sought to determine if supported ionic liquid membranes (SILMs), which had been tested by a handful of other researchers, had the potential to separate CO_2 from streams containing H_2 under conditions relevant to IGCC processes. Results with membranes similar to those described in the literature proved promising, and it was discovered that support, rather than transport medium, performance limited temperature. An effort to improve support stability was undertaken and revealed polymeric support materials capable of operation at conditions beyond those expected in the low temperature water-gas shift reactor. Parallel to support development work at NETL, project researchers at Notre Dame worked to develop improved ionic liquid transport media based on early membrane testing. The goal was to improve permeance, selectivity (CO_2 permeance/H_2 permeance) and temperature of operation. That effort culminated in the demonstration of the first ionic liquid based facilitated transport membrane that showed performance significantly superior to competing polymeric membranes and led to a well-defined path forward with respect to performance improvement. While ionic liquid development along that path continues, NETL is working to develop more practical membranes which capture the advantageous properties of polymeric membranes while maintaining the superior performance of supported ionic liquids. Two approaches are being examined: membranes based on polymerized versions of the ionic liquids and dense polymer films containing pockets of ionic liquid. The effect of fuel gas contaminants such as H_2S on these materials is also currently being studied. Future steps will include a detailed systems analysis, extended test runs to determine long term membrane stability under simulated fuel gas conditions and the location of industrial partners with the expertise necessary to fabricate materials developed in the project into membrane modules for slipstream plant testing.