CRTD-85

National Energy Technology Laboratory

Final Report
Carbon Sequestration
Project Review Meeting

Greater Pittsburgh International Airport Hyatt Hotel
September 25-28, 2006

Volume I
Meeting Summary and Recommendations

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Work Done Under
RDS Prime Contract Number DE-AM26-04NT41817 (Task/Subtask 311.01.07)

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The work performed on this task/subtask was completed under Research and Development Solutions, LLC (RDS) Prime Contract Number DE-AM26-04NT41817, Subtask 311.01.07 for the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). The period of performance under this prime contract with NETL for this subtask is December 1, 2004 through April 30, 2007. To assist in the performance of this subtask, RDS has subcontracted with West Virginia University (under Task/Subtask 41817M2106) which, in turn, has further subcontracted with ASME.

EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE), under the Carbon Sequestration Program administered by the National Energy Technology Laboratory (NETL) within the Office of Fossil Energy, is seeking a better scientific understanding of the capture and storage of carbon dioxide (CO_2). One of the goals of this program is to develop cost-effective and environmentally sound technologies which will reduce greenhouse gas emissions and help to stabilize overall atmospheric concentrations 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 have initiated a series of annual Project Review meetings with independent, technical experts to assess ongoing research projects and, where applicable, to make recommendations for improvement.

In cooperation with the National Research Center for Coal and Energy (NRCCE) at West Virginia University, the American Society of Mechanical Engineers (ASME) convened a panel of eight leading government, academic, and industry experts on September 25-28, 2006 to conduct a two and one-half day review of selected carbon sequestration research projects supported under the NETL program.

Overview of Carbon Sequestration Research Categories

The Review Panel completed evaluations of projects in the following six carbon sequestration research categories:

- Capture of CO_2
- Sequestration –Terrestrial
- Sequestration – Geologic
- Measurement, Monitoring and Verification
- Non-Greenhouse Gas Concepts
- Regional Carbon Sequestration Partnership

A copy of the *Carbon Sequestration Technology Roadmap and Program Plan* was made available as a reference document for panel members and can be accessed at:

http://www.netl.doe.gov/publications/carbon_seq/refshelf.html

Overview of Project Review Process

NETL requested that ASME assemble a project review panel to obtain recommendations from technical experts on how to improve the performance, management, and overall results from its individual research projects. These recommendations and action items would then be considered by the individual DOE project managers for incorporation into each research project.

Eighteen projects were selected by NETL to be reviewed in a total of 16 presentation sessions during this review process. These projects are summarized in the following Table 1. Three related geologic sequestration projects were combined into one presentation due to time constraints. Each project team prepared an 11-page summary of work completed to date for review by the independent panel. With these summaries available to the Review Panel prior to the September 25-28, 2006 meeting, all panel members were encouraged to submit questions in advance of the meeting so they could be forwarded to the respective PIs and then addressed during the formal presentations at the review meeting. At the meeting, each research team made a 30-minute presentation (or longer for larger or joint projects) that was followed by a 10-minute question and answer session with the reviewers. Using a predetermined set of review criteria, each panel member evaluated all 18 projects and provided written review comments following a 25-minute group discussion of each project.

Table 1. 2006 NETL Carbon Sequestration Projects					
Category Number	**Project Number**	**Title**	**Lead Organization**	**Principal Investigator**	**Project Duration**
C-1	OST-14-06	Novel CO_2 Capture Concept	National Energy Technology Laboratory	Robert Dilmore	10/1/2005 – 9/30/2006
C-2	NT42120	Novel Dual-Function Membranes	University of New Mexico	C. Jeffrey Brinker	8/23/2004 – 8/22/2007
C-3	NT42122	Ionic Liquids as Novel CO_2 Absorbents	University of Notre Dame	Edward J. Maginn	7/16/2004 – 7/15/2007
C-4	NT42119	Fabrication of Hydrogen Selective Silica Membranes	University of Minnesota	Michael Tsapatsis	$8/1/2004 – 7/31/2007
C-5	FWP49539	Capture/Utilization/Disposal Options for PC Boilers	Argonne National Laboratory	Richard D. Doctor	9/2000 – 9/2007
C-6	NT42430	Oxygen-Fired CO_2 Recycle	Southern Research Institute	Thomas K. Gale	9/27/2005 –9/26/2008
T-1	NT42431	Microbial Mitigation of Landfill Gas	University of Michigan	Jeremy D. Semrau	7/1/2005 – 6/30/2008
T-2	NT42433	Bio-Tarp for Landfill Gas	University of North Carolina	Helene Hilger	8/1/2005 – 7/31/2008
T-3	NT42437	Digital Elevation Models to Detect Forest Carbon	Winrock International	Kenneth MacDicken	8/1/2005 – 7/31/2007
G-1	G-204 FEW0056 FEAA0045	GEO-SEQ	Lawrence Berkeley National Laboratory	Sally M. Benson	10/1/2005 – 9/30/2009
G-2	OST-14-06	CO_2 Adsorption in Coal Seams	National Energy Technology Laboratory	Angela Goodman	10/1/2004 – 10/1/2008
G-3	NT41148	CO_2 Sequestration in Unmineable Coal Seams	CONSOL Energy, Inc.	Robert E. Douglas	10/1/2001 – 12/31/2008
MMV-1	NT42212	Low-Cost Instrument for Monitoring Atmospheric CO_2	California Institute of Technology	William A. Goddard III	10/1/2004 – 5/31/2008
MMV-2	FWP04FE04-06	CO_2/Water/Rock Interactions	Los Alamos National Laboratory	J. William Carey	10/1/2003 – 9/30/2007
Non-GHG	NT42432	Intelligent Bioreactor Management Information System	University of Delaware	Paul T. Imhoff	6/1/2005 – 5/31/2008
RP	NT42589	Midwest Regional Carbon Sequestration Partnership	Battelle Science and Technology International	David Ball	10/1/2006 – 9/30/2009

Projects were evaluated against 10 pre-established criteria described below. Panel members rated the progress of the projects against these criteria:

- Project accomplishments *do not meet* expectations,
- Project accomplishments *meet* expectations, or
- Project accomplishments *exceed* expectations.

There are two areas where principal investigators have difficulty in responding to the concerns of the Review Panel: preparing economic analyses (criterion #6) and carefully considering all of the possible adverse effects of their project (criterion #9). The panel recommends that future projects be required to include a greater emphasis on these areas in their approved statements of project objectives and deliverables. For the remaining eight criteria, the average for all projects reviewed at this meeting meets or exceeds expectations over 88 percent of the time.

In addition to this scoring exercise, panel members provided feedback on project Strengths, Weaknesses, Recommendations, Action Items, and General Comments. Review Panel recommendations will assist NETL in providing feedback and guidance to the Principal Investigators (PI) for each project.

Summary of Reviewer Scoring Across All 16 Project Presentations

Criterion:	Does Not Meet Expectations	Meets Expectations	Exceeds Expectations
Project Merit			
1: Scientific and Technical Merit	12.5%	57.7%	29.8%
2: Anticipated Benefits if Successful	8.6%	54.4%	37.1%
Approach and Progress			
3: Technical Approach	8.6%	66.2%	25.2%
4: Rate of Progress	7.0%	75.0%	18.0%
5: Knowledge of Related Research	7.8%	65.3%	26.9%
6: Economic Analysis	23.4%	66.7%	9.8%
7: Utilization of Government Resources	10.2%	61.0%	28.8%
Deployment Considerations			
8: Commercialization Potential	11.9%	66.6%	21.4%
9: Possible Adverse Effects Considered	16.4%	78.8%	4.8%
10: Attention to Constituent's Concerns	8.7%	86.4%	5.7%

For More Information

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I. INTRODUCTION

For the fifth consecutive year, the American Society of Mechanical Engineers (ASME) was invited to provide an independent, unbiased, and timely review of selected projects within the Carbon Sequestration Program of the U.S. Department of Energy, Office of Fossil Energy. This report contains a summary of the findings from that review during 2006.

Compliance with OMB Requirements

The Carbon Sequestration Project Review process 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 U.S. Department of Energy, the Office of Fossil Energy, and the National Energy Technology Laboratory (NETL) are fully committed to improving the quality and results of projects in the Carbon Sequestration Program.

ASME was selected as the independent contractor to review 18 projects that were presented in 16 presentation sessions. ASME performed this project review work as a subcontractor to Research and Development Solutions, LLC (RDS), a DOE prime contractor. The 18 projects reviewed were selected by NETL. Principal Investigators (PIs) for each selected project submitted an 11-page written summary of the status of their projects, received questions from panel members prior to the review meeting, and then made an oral presentation to the panel selected by 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 two volumes. The present volume (Volume I) prepared by ASME provides a general overview of findings from the Project Review and is available to the public. The second volume (Volume II) prepared by ASME contains evaluations and reviewer comments concerning each project reviewed. It is not distributed publicly due to the nature of the document. A third volume (Volume III), prepared by NETL, summarizes the responses of the Principal Investigators to the "Recommendations and Action Items" proposed by the ASME review panel.

ASME Center for Research and Technology Development

All requests for project reviews are organized under the ASME Center for Research and Technology Development (CRTD). Director of Research, Dr. Michael Tinkleman, with advice from the ASME Chair, Research, selects an Executive Committee of senior ASME members that is responsible for reviewing and selecting all Review Panel members and ensuring there are no conflicts of interest within the panel or the review process. In consultation with NETL managers, ASME is responsible for preparing the review meeting agenda, advising the Principal Investigators 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 Project Review Methodology used for this project is provided in Appendix A. A copy of the Meeting Agenda is provided in Appendix B and an introduction to the Project Review Panel Members for this project is provided in Appendix C.

Review Criteria and Reviewer Evaluation Sheets

In cooperation with the West Virginia University (WVU) National Research Center for Coal and Energy (NRCCE), the ASME team developed a set of agreed upon review criteria to be applied to the projects under review at this meeting and then prepared an evaluation sheet based on these criteria for use by the Review Panel. Written reviewer comments were also collected and the panel members spent time in private assessing the strengths and weaknesses of each project before providing both recommendations and action items to NETL. A more detailed explanation of this process and a sample Reviewer Evaluation Sheet are provided in Appendix D.

The following sections of this report summarize findings from the Project Review Meeting and are organized as follows:

II. General Reviewer Comments on the DOE Carbon Sequestration Technology Roadmap
    A summary of general comments from reviewers about the overall DOE Carbon Sequestration Technology Roadmap.

III. Summary of Projects Reviewed in 2006
    A summary description of the 16 presentations from the 18 projects reviewed this year.

IV. An Overview of the Evaluation Process in 2006
    A brief overview of evaluations along with analysis and recommendations.

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

II. GENERAL REVIEWER COMMENTS ON THE DOE CARBON SEQUESTRATION TECHNOLOGY ROADMAP

The Review Panel at this meeting focused only on the evaluation of the projects selected by DOE for review. This meeting was not intended to be a review of the entire DOE Carbon Sequestration Program. However, the current *DOE Carbon Sequestration Technology Roadmap and Program Plan* was provided to the reviewers prior to the meeting and, on the first evening of this session, panel members were given a briefing on the document as both background and context for the specific projects they were to review. At the conclusion of the meeting, reviewers were asked to reflect on the meeting in general. Following is a summary of reviewer comments about the Sequestration Roadmap. These comments are not intended to go beyond the limited scope of the Project Review. They are provided by the reviewers, in good faith, that they might be useful to DOE managers.

The Roadmap as a Strategic Plan

The challenge of reducing CO_2 emissions and sequestering carbon is a very large problem to be solved over the long term. It is a century-scale problem. The research being conducted in this Program will drive the policy options that will be considered for decades to come.

This year Project Reviewers were uniformly complimentary of the DOE Sequestration Roadmap. One called it, simply, a "beautiful" document. Two others said that they were taking the document back to their own organizations as an example of how best to prepare such a document. One professor said that he was intending to use the document in an advanced management class as an introduction to energy issues that every high level manager should know.

One Project Reviewer, who has watched the Program grow since the 1990s, commented in detail about the growing maturity and substance of the Program. Several reviewers commented that the Program is clearly addressing problems of national significance and seeing viable solutions to those problems. Because the Japanese sequestration program has been diminishing over the last several years, another reviewer pointed out, the world is now watching this Program as the leading program on sequestration in the world.

Another reviewer, addressing the strategic importance of this Roadmap, pointed out that this Program is addressing the unique government role of laying out the technology base now that will become the basis for future government action in this area. Because there are currently so few economic drivers for sequestration, another reviewer pointed out that, if there is going to be a significant implementation of CO_2 capture and sequestration, the government will have to take some forcing action.

Two reviewers offered comments about new strategic initiatives that should be considered for future Roadmaps. The first comment suggested that it was time for the Program to focus more directly on viewing CO_2 storage capacity as a resource of the nation and, in that light, to complete a credible resource assessment of the nation's storage capacity. Although some of the

Regional Partnerships are working in this area, the reviewer concluded there does not yet seem to be an effort underway to do a full-scale national resource assessment.

Secondly, because enhanced oil recovery is the logical first step for sequestering truly significant quantities of CO_2, another reviewer proposed that the Program should be building much stronger strategic ties to the oil and gas industry.

The Roadmap as a Portfolio of Projects

Those reviewers who have participated in this review over four or five years all commented that the quality of projects has been steadily increasing and that the group of projects reviewed this year was the best to date. The quality of the presentations has also been increasing and the number of flaws upon which to comment has been decreasing (with one or two notable project exceptions).

One reviewer commented that the portfolio of projects must always have a mix of successes and failures. The Program has clearly had many successes. Several of the projects reviewed in previous years have shown marked application or market success. However, to be a true R&D Program, there must be many risks taken and "failures" as a result. This reviewer cautioned that the failures are just as valuable for what we learn from them as the successes are. The reviewer suggested that NETL, in balancing the portfolio, not be afraid to take risks and not be too apologetic about failures – so long as we can learn from them.

Another reviewer complimented the Program for having a diverse portfolio of projects where the skills of the research teams are well matched to the projects at hand. For example, the breakthrough projects have researchers with great basic science skills who also have the ability to "think outside the box." Projects that are further toward demonstration are displaying technology skills, organization skills, and knowledge of cost targets.

An additional reviewer suggested that it would be helpful to the reviewers if the portfolio could also be presented in "classes" or groups of projects based on the general potential of the project to reduce CO_2 in the atmosphere. Even if grouped by orders of magnitude of potential sequestration, it would be helpful to see that projects with the greatest potential impact are receiving adequate resources.

Several reviewers made comments regarding specific groups of projects in the current portfolio:

- Several reviewers specifically commented on how much they liked the breakthrough projects presented this year. These projects demonstrated a clear application of excellent science and chemistry.
- Three reviewers commented that CO_2 will never be collected entirely at point sources (by scrubbers) so it is essential that the Program continue to have terrestrial and biological projects in the portfolio.
- Another reviewer commented that the landfill-related projects in the portfolio represented an excellent near-term opportunity for noticeable results based on the fact that they are cheap, done with generally available materials, and relatively easy to do.

- In the area of remote sensing for terrestrial projects, one reviewer suggested that the Program start over. Current projects in the Program do not represent the current state-of-the-art in either public or classified technologies. Perhaps a "mini" conference on this topic with leaders in the field could give the Program a new set of projects in this category for the portfolio.

Projects are Being Managed Well Against the Roadmap

Many of the reviewers commended the Program management for their good leadership. Given the very broad range of projects in the portfolio – from super science to more fundamental field projects – Program management was complimented for being able to successfully manage a range of diverse research projects.

Several reviewers commented that it is critical that the Program continue to use realistic cost targets as a principal means to guide project selection and management. This aspect of portfolio management has been getting better over the years that projects have been reviewed and the Program managers are encouraged to continue this effort.

While using cost targets is critical, another reviewer cautioned that it is important not to use them too harshly as an "on/off" switch. For example, if a project is having trouble meeting cost targets and there is no other project in this category that is meeting cost targets, it might be advisable to give the troubled project extra help in trying to meet cost targets rather than terminating it altogether.

Despite the success of many individual projects, several reviewers suggested that managing the Program against the Roadmap might be improved by coaching individual projects to be more on the overall Program team. There appeared to be many opportunities for "cross fertilization" among projects that could enhance the overall Program but that the individual project leaders did not yet realize the value of such team success.

Finally, one of the reviewers asked for a clearer discussion on how the core R&D of the Sequestration Program links to the Regional Partnerships. It would be good to see this in connection with the overall portfolio of projects and it would be good for each presenter of a Regional Partnership to address this topic directly.

III. SUMMARY OF PROJECTS REVIEWED IN 2006

The projects that were reviewed by the ASME independent panel represent a sample of the total number of projects within each of six Carbon Sequestration Program categories. Twelve months was considered by NETL to be the minimum length of time needed before a project would have generated enough performance information to have it evaluated. These evaluations also provided valuable insight on the technology developed and the project methodology for a nearly-completed project so that lessons learned could be available for future or ongoing similar projects.

During the 2006 Project Review, as well as the annual reviews conducted in previous years, NETL selected a number of candidate projects for review that had already been reviewed in prior years. This approach enables NETL to constantly monitor research progress made in its sequestration projects and to evaluate how well the Principal Investigators are addressing recommendations/action items proposed by the annual Review Panels for improving those projects.

The projects reviewed in the 2006 Carbon Sequestration Project Review Meeting within each of the six different categories are as follows:

Section I: Capture of CO_2

C-1: OST-14-06
Novel CO_2 Capture Concept
CO_2 Scrubbing Using the Enzyme Carbonic Anhydrase
Robert Dilmore—NETL (with University of Pittsburgh)

C-2: NT42120
Novel Dual-Function Membranes
C. Jeffrey Brinker—University of New Mexico

C-3: NT42122
Ionic Liquids as Novel CO_2 Absorbents
Edward J. Maginn—University of Notre Dame

C-4: NT42119
Fabrication of Hydrogen Selective Silica Membranes
Michael Tsapatsis—University of Minnesota

C-5: FWP49539
Capture/Utilization/Disposal Options for PC-Boilers
Richard D. Doctor—Argonne National Laboratory

C-6: NT42430
Oxygen-Fired CO_2 Recycle
Thomas K. Gale—Southern Research Institute

Section II: Sequestration—Terrestrial

T-1: NT42431
Microbial Mitigation of Landfill Gas
Jeremy D. Semrau--University of Michigan

T-2: NT42433
Bio-Tarp for Landfill Gas
Helene Hilger—UNC Charlotte

T-3: NT42437
Digital Elevation Models to Detect Forest Carbon
Kenneth MacDicken—Winrock International

Section III: Sequestration—Geologic

G-1: GEO-SEQ
G-204 –LBNL; FEW0056-LLNL; FEAA0045-ORNL
Sally M. Benson—Lawrence Berkeley National Laboratory

G-2: OST-14-06
CO_2 Adsorption in Coal Seams
Angela Goodman—National Energy Technology Laboratory

G-3: NT41148
CO_2 Sequestration in Unmineable Coal Seams
Robert E. Douglas—CONSOL Energy, Inc.

Section IV: Measurement, Monitoring and Verification

MMV-1: NT42212
Low-Cost Instrument for Monitoring Atmospheric CO_2
William A Goddard III—California Institute of Technology

MMV-2: FWP04FE04-06
CO_2/Water/Rock Interactions
J. William Carey—Los Alamos National Laboratory

Section V: Other Concepts

Non-GHG: NT42432
Intelligent Bioreactor MIS
Paul T. Imhoff—University of Delaware

Section VI: Regional Partnerships

RP: NT42589
Midwest Regional Carbon Sequestration Partnership
David Ball—Battelle Science and Technology International

A short summary of each of the above projects is presented in Appendix E. In addition, a compact disk containing electronic files of presentation material used by the Principal Investigators at the review meeting is included in hard-copy versions of this report. The presentation materials in Volume I will be available electronically at the NETL web site:

http://www.netl.doe.gov/technologies/carbon_seq/index.html

- Under section marked "Analysis", click on "Systems"
- In section marked "Peer Review", click on "2006 Carbon Sequestration Project Review Volume 1"

IV. AN OVERVIEW OF THE EVALUATION PROCESS IN 2006

The ASME team, in cooperation with NETL and with input from the Project Review panel, continues to enhance and refine the process used for evaluating the projects selected for the 2006 Project Peer Review Meeting. A copy of the Reviewer Evaluation Sheet and an explanation of the process are provided in detail in Appendix D. The criteria against which the projects scored well are not discussed since the focus of this section is to highlight the areas that need improvement.

The following table shows, on average, how the composite set of projects reviewed was rated against the ten review criteria. Each cell represents the average across all reviewers. For example, in regard to "Technical Merit," the reviewers collectively found that 57.7 percent of projects met expectations, 29.8 percent of projects exceeded expectations, and 12.5 percent did not meet expectations.

Criterion:	**Does Not Meet Expectations**	**Meets Expectations**	**Exceeds Expectations**
Project Merit			
1: Scientific and Technical Merit	12.5%	57.7%	29.8%
2: Anticipated Benefits if Successful	8.6%	54.4%	37.1%
Approach and Progress			
3: Technical Approach	8.6%	66.2%	25.2%
4: Rate of Progress	7.0%	75.0%	18.0%
5: Knowledge of Related Research	7.8%	65.3%	26.9%
6: Economic Analysis	23.4%	66.7%	9.8%
7: Utilization of Government Resources	10.2%	61.0%	28.8%
Deployment Considerations			
8: Commercialization Potential	11.9%	66.6%	21.4%
9: Possible Adverse Effects Considered	16.4%	78.8%	4.8%
10: Attention to Constituent's Concerns	8.7%	86.4%	5.7%

Criteria where Projects Need Significant Improvement

There is one review criterion against which projects continue to struggle: #6 Economic Analysis. In 2005, 26 percent of projects reviewed "did not meet expectations" against this criterion. This year, 2006, that finding was improved only modestly. Still, 23.4 percent of projects "do not meet expectations" against this criterion. Given the discussion in Section II about the importance of managing the portfolio against reasonable cost targets, this remains an identified weakness in the Program.

The Reviewers were complimentary that the discussions in 2006 of economics or cost targets were starting to show up but that they were not consistent. Even if not called "economics," it would have been helpful for projects contemplating application if they had presented even rudimentary material flow diagrams and quantity estimates.

More effort needs to be spent to translate highly technical discussions into terms that can be understood and discussed by financial people. As the Program continues to move closer to implementation for a number of projects in the portfolio, the input of financial experts will become critical in achieving market implementation and success.

As in all previous years, only a small number of projects provided a compelling economic analysis. In 2005, 6.9 percent of projects were commended as "exceeding expectations" in this category. In 2006, 9.8 percent of projects were recognized as "exceeding expectations" for this criterion.

<u>Something Special for the Regional Partnerships</u>

According to several reviewers, after five years of effort on the Regional Partnerships, it is appropriate to have a broad review of them. Such a review should focus on whether each partnership is successfully moving towards its initially intended goals and, if not, make recommendations for any mid-course corrections.

Several reviewers addressed the logistics for future Regional Partnership reviews. Regional Partnerships manage a collection of multiple projects. One reviewer advised that the Review Panel as currently constituted and the review process itself is not appropriate for reviewing a Regional Partnership. A Partnership needs a different kind of review, possibly including site visits, interviews, a management assessment, a marketing assessment, and other review criteria. Another reviewer observed that trying to review a Partnership within just a 45-minute time slot is extremely difficult and principal investigators can present only minimal amounts of technical material for evaluation given these time constraints. These concerns should be addressed in planning any future Regional Partnership reviews.

V. PROCESS CONSIDERATIONS FOR FUTURE PROJECT REVIEWS

Both Review Panel members and the DOE managers involved in the Project 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. Following is a brief summary of ideas recommended for use in planning future project review sessions.

General Process Comments

The reviewers were unanimous in their opinion that the Review Panel process as it is currently constituted and run is excellent and shouldn't be altered. The support staff is superb and is implementing the process as smoothly as can be imagined.

In addition to acknowledging respect for the skills each reviewer brings to the table, nearly all commented that the collective knowledge of the group – based on the ability of many reviewers to participate multiple times – is clearly adding to the overall efficiency of the group in reviewing projects. It is also contributing to the consistency of scoring and the ability to provide good recommendations and action items.

Regarding the commitment of time to participate in these panels, several reviewers noted that they had about reached the limit of what is possible. Including preparation, travel time, and the review panel itself, the time commitment now meets or exceeds six full days. Most reviewers stated that the honorarium is certainly appreciated but that it does not cover the true cost of their time.

Due to other commitments in general, and especially for the academic participants who must juggle the start of the academic year with the Fall timing of the Project Review, announcing the dates of the Review as soon in the year as possible is greatly appreciated.

Selecting Projects for Review

Reviewers continue to agree that the best time to review a project is after it has had sufficient time to get started and make some progress but well before its end so that the comments of reviewers can help to improve the project. Unless there are special circumstances, each project should be reviewed only after a year or so of initial activity and a year or more before its conclusion.

Most reviewers agreed that it is good to see a representation of all Program categories at each review session. This year offered another good mix of sequestration projects. It is hoped that over the course of several years, all projects in the Program portfolio will have the benefit of this review.

Pre-Meeting Documentation

The 11-page, pre-meeting project summaries which include the 3-page standardized opening pages have become an essential part of the review process. Reviewers liked the requirement for a bibliography but continued to ask that it be kept within the prescribed limits.

Distributing the project summaries on a CD this year was very well received by the reviewers and all asked that it continue. Getting these materials as early in the review process as possible is also very much recommended and appreciated.

Two reviewers commented that the presentations by the PIs at the review meeting often differ substantially from the 11-page project summary provided before the meeting. This needs to be clarified in the pre-meeting instructions to PIs. Although the 11-page summary is an introduction to the project and PIs should be free to move beyond this introduction in their presentations, PIs should also be advised that making a presentation at the review meeting that is too dissimilar to the 11-page summary could lead to confusion and potentially negative comments.

Pre-Review Questions Back to the PIs

This was the second year of the two-step process whereby reviewers were given the opportunity to send questions back to the PIs after having read the 11-page summaries and before attending the Review Meeting. This process appears to help PIs focus their presentations and it clearly helped reviewers understand more about the complex projects quickly. This two-step process is currently planned to be a part of future reviews. Both reviewers and PIs commented that it would be helpful if the turn-around time could be extended.

Meeting Agenda

Moving the presentations by DOE staff to the evening before the start of the project reviews was very well received by all reviewers. Also, the differing material of both presentations was very well received. Several reviewers commented that the Sequestration Overview – presented by Sean Plasynski, NETL Technology Manager for the Carbon Sequestration Program – was excellent for setting the general context for the projects to be reviewed and for bringing the full attention of the reviewers to the subject at hand before the start of the project reviews. The feedback on actions taken from the previous review – presented by Jose Figueroa, NETL Project Manager – was equally well received because it showed the commitment of management to having a coherent set of Program goals and to carrying them out. Reviewers appreciated seeing how their advice fit into this process and that it was taken seriously.

Several reviewers, from the earliest project review meetings, commented that the use of 16 to 17 time slots on the agenda made it possible to complete the reviews as expected by DOE management – in contrast to the early years of the review when too many project reviews were attempted in the time allowed for the meeting.

Presentations

The PIs are generally to be complimented since most of them are making a sincere effort to address all of the review criteria against which they are being judged. However, some still are not. The instructions to PIs should continue to be worded strongly that failure to address all of the review criteria will result in low scores.

All reviewers commented that the quality of the presentations continues to improve each year. One reviewer warned future PIs to avoid undocumented science or excessive hype.

Review Criteria

The review criteria used to assess the selected projects remain useful and generally well received. However, as one reviewer pointed out, they remain subject to interpretation. For example, the measure of "substantial progress" remains to be judged by each reviewer. In fact, over several years and from seeing multiple projects, many of the reviewers are now have a decent metric for making this judgment.

As discussed at all previous reviews, one reviewer asked that for projects at the very earliest stage of research, it be made possible for reviewers to select "Not Applicable" against some of the more application-oriented review criteria – like economics. This always starts a lively discussion. This proposal should be considered in making revisions, or not, to the review criteria before the next review meeting.

Project Discussions

The format of discussing each project individually after its presentation was confirmed again this year as the best approach. More time for Q&A is always desirable but the current time allocations appear to be at least sufficient. It is important to have both the group discussion of each project and individual written comments from reviewers. The written reviewer comments are also very useful in preparing review comments for each project.

APPENDIX

A. ASME Project Review Methodology

B. Meeting Agenda

C. Project Review Panel Members

D. Reviewer Evaluation Sheet

E. Project Summaries

APPENDIX A
ASME Project 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 long years of experience, the Society has developed a standardized approach to reviewing research projects. The purpose of this section is to give a brief overview of the review procedure established for the DOE/NETL Carbon Sequestration Project Review.

ASME Knowledge and Community Sector

One of the five sectors responsible for the activities of ASME's 125,000 members worldwide, the Knowledge and Community (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

The mission of the Center for Research and Technology Development (CRTD) is to effectively plan and manage the collaborative research activities of ASME to meet the needs of the mechanical engineering profession as defined by the ASME members. The 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 Project 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

The Board on Research and Technology Development (BRTD) governs the activities of the Center for Research and Technology Development (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.

CO_2 Project Review Executive Committee

For each set of projects to be reviewed, the BRTD convenes a Project 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 Project Review Executive Committee. They must have experience relevant to the program being reviewed. Members of the CO_2 Project Review Executive Committee were as follows:

- Dr. Adnan Akay, Chair. Dr. Akay is currently Division Director, Civil and Mechanical Systems at 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 Vice-President for Environment and Transportation on the ASME Council on Engineering. 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. He was previously a Vice-President of the ASME Energy Conversion Group and is on the ASME Energy Committee. Mr. Laudenat is well versed on the issue of emissions from electric generating plants.

CO_2 Project Review Panel

The CO_2 Project Review Executive Committee accepted resumes for proposed Review Panel members from the DOE Program staff, from CRTD, and from a limited call to ASME members with relevant experience in this area. From these alternatives, the ASME Project Review Executive Committee oversaw the selection of an eight-member Project 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: forestry; earth chemistry; geology; CO_2 capture; clean coal technology; and measurement, monitoring, and verification.

Meeting Preparation and Logistics

The DOE Project Manager announced the upcoming project review two months ahead of the meeting. Prior to the meeting, each project team to be reviewed was asked to submit an 11-page report summarizing the goals of their project and accomplishments to date. A standard set of specifications for preparing this document was provided by CRTD. These documents were

collected and sent to the Project Review Panel for their 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 review meeting.

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

Project Presentations, Evaluations, and Discussion

At the September 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 2½-day review meeting. After each presentation, the project team interacted with the Review Panel for 10 minutes of questions and answers.

Following each presentation, the Review Panel spent 25 minutes considering the material that had been presented. To start, each reviewer scored the project against a set of predetermined review evaluation criteria. Ten criteria were used:

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

For each of these categories the reviewers assessed whether the project "Met Expectations," "Exceeded Expectations," or "Did Not Meet Expectations." These categories are further defined in Appendix D.

After determining their individual evaluations, the Review Panel members each provided written comments about the project. Finally, the 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.

The agenda for this meeting showing the organization of project presentations by category is provided in Appendix B.

APPENDIX B
Meeting Agenda

2006 Carbon Sequestration Project Review Meeting

Monday Evening Program—9/25/06

Room: Wright A&B

4:00-6:00	Kickoff Briefing with Project Reviewers [1]	
	Orientation Briefing	Tinkleman/Hart
	DOE/NETL 2006 CO_2 Sequestration Overview	Plasynski
	2005 Feedback Review & Update	Figueroa

Room: Yeager A&B

6:30-7:30 Registration and Welcome Reception

[Note: There will be a modest registration fee to cover the cost of meals.]

Tuesday Program—9/26/06

Presenters Ready Room is available all day for testing Laptop and LCD Projection. – Foerster Boardroom

Room: Allegheny ABC

7:00-7:55	Continental Breakfast	
7:55-8:00	Call To Order	Hart

Session 1: Capture

8:00-8:30	**C-1: OST-14-06--Novel CO_2 Capture Concepts**	**OSTA**
8:30-8:40	Q&A	
8:40-9:05	Discussion, Evaluation, and Written Comments [2]	
9:05-9:35	**C-2: NT42120—Novel Dual Function Membranes**	**U of New Mexico**
9:35-9:45	Q&A	
9:45-10:10	Discussion, Evaluation, and Written Comments	
10:10-10:20	Break	

[1] This session from 4 PM to 6 PM on Monday is open only to panel members, selected DOE personnel, and review coordinators.

[2] Only panel members, selected DOE personnel, and review coordinators will be permitted in the meeting room for these sessions. All other visitors and principal investigators will be asked to wait outside the meeting room while the panel engages in confidential discussion regarding each project presented.

10:20-10:50	**C-3: NT42122—Ionic Liquids as Novel Absorbers**	**U of Notre Dame**
10:50-11:00	Q&A	
11:00-11:25	Discussion, Evaluation, and Written Comments	
11:25-11:55	**C-4: NT42119—Fabrication of Silica Membranes**	**U of Minnesota**
11:55-12:05	Q&A	
12:05-12:30	Discussion, Evaluation, and Written Comments	
12:30-1:30	Lunch (Provided for Reviewers) – Room: Earhart A	
1:30-2:00	**C-5: 49539—Capture/Utilization/Disposal Options**	**ANL**
2:00-2:10	Q&A	
2:10-2:35	Discussion, Evaluation, and Written Comments	
2:35-3:05	**C-6: NT42430—Oxygen-Fired CO_2Recycle**	**Southern Res Inst**
3:05-3:15	Q&A	
3:15-3:40	Discussion, Evaluation, and Written Comments	
3:40-4:00	Break	

Session 2: Sequestration—Terrestrial

4:00-4:30	**T-1: NT42431—Microbial Mitigation of Landfill Gas**	**U of Michigan**
4:30-4:40	Q&A	
4:40-5:05	Discussion, Evaluation, and Written Comments	
5:05	Adjourn	

Room: Lindberg A&B

6:00	Reception
7:00	Dinner for All Participants

Wednesday Program—9/27/06

Presenters Ready Room is available all day for testing Laptop and LCD Projection. – Foerster Boardroom

Room: Allegheny ABC

7:00-7:55	Continental Breakfast	
7:55-8:00	Call To Order	Hart

Session 3: Sequestration—Geologic

8:00-8:30	**G-2: OST-17-06—Adsorption Studies**	**OSTA**
8:30-8:40	Q&A	
8:40-9:05	Discussion, Evaluation, and Written Comments	
9:05-9:35	**G-3: NT41148—Sequestration in Coal Seams**	**CONSOL**
9:35-9:45	Q&A	
9:45-10:10	Discussion, Evaluation, and Written Comments	
10:10-10:20	Break	

Session 4: Measurement, Monitoring and Verification

10:20-10:50	**MMV-1: NT42212—Instrument for On-Site Monitoring**	**Cal Tech**
10:50-11:00	Q&A	
11:00-11:25	Discussion, Evaluation, and Written Comments	
11:25-11:55	**MMV-2: 04FE04-5—CO_2/Water/Rock Interaction**	**LANL**
11:55-12:05	Q&A	
12:05-12:30	Discussion, Evaluation, and Written Comments	
12:30-1:20	Lunch (Provided for Reviewers) – Room: Earhart A	

Session 5: Sequestration—Geologic

1:20-2:05	**G-1: GEOSEQ**	
	* **G-204**	**LBNL**
	*** FEW0056**	**LLNL**
	*** FEAA0045**	**ORNL**
2:05-2:20	Q&A	
2:20-2:50	Discussion, Evaluation, and Written Comments	
2:50-3:05	Break	

Session 6: Sequestration—Terrestrial

3:05-3:35	**T-2: NT42433—Bio-Tarp for Landfill Gas**	**U of NC**
3:35-3:45	Q&A	
3:45-4:10	Discussion, Evaluation, and Written Comments	
4:10-4:40	**T-3: NT42437—Digital Evaluation of Forest Carbon**	**Winrock**
4:40-4:50	Q&A	
4:50-5:15	Discussion, Evaluation, and Written Comments	
5:15	Adjourn	

Room: Lindbergh A&B
6:00-7:00 Reception (Dinner on your own.)

Thursday Program—9/28/06

Room: Allegheny ABC
7:00-7:55 Continental Breakfast
7:55-8:00 Call To Order Hart

Session 7: Other Concepts

8:00-8:30 **Non-GHG: NT42432—Intelligent Bioreactor MIS** **U of Delaware**
8:30-8:40 Q&A
8:40-9:05 Discussion, Evaluation, and Written Comments

9:05-9:50 **RP: NT42589 - Midwest Regional Carbon Sequestration Partnership** **Battelle Columbus**
9:50-10:05 Q&A
10:05-10:30 Discussion, Evaluation, and Written Comments

10:30-10:40 Break

Session 8: Closing Session [3]

10:40-12:05 Summary Comments from Reviewers (12 minutes each)
12:35 Adjourn
12:45 Wrap-up Luncheon for Review Panel

[3] This session is open only to panel members, selected DOE personnel, and review coordinators.

APPENDIX C
Project Review Panel Members

After reviewing the wide range of scientific and engineering related issues represented by the 18 projects to be reviewed, the CRTD staff and the ASME Project 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 Project Review Panel:

- Advanced Biology
- Chemistry (both hydration and carbonates)
- Clean Coal Technology
- Computer Modeling (both chemical and geologic)
- Design Engineering/Systems Analysis
- Environmental Economic Analysis
- Mineral Geology
- Petroleum Engineering
- Petroleum Geology
- Plants/Forestry/Soils

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

Considering the Areas of Expertise defined above, the CRTD carefully reviewed the resumes of all those who had previously served on a CO_2 Peer Review Panel, acknowledging the benefit of their previous experience in this regard. It was determined that many of those who had served before were well qualified to do so again.

Appropriate resumes were submitted to the CO_2 Project Review Executive Committee for review. Eight members were selected for the 2006 Project Review Panel:

- Dr. John R. Benemann, Consultant
- Dr. Garry Brewer, Yale University
- Dr. Robert C. Burruss, US Geological survey
- Dr. John F. Clarke, Department of Homeland Security
- Mr. Bruce Reynolds, Idaho National Laboratory
- Dr. Ruben Simoyi, Portland State University
- Dr. David Thomas, Consultant
- Dr. Raymond L. Zahradnik, Consultant

A brief summary of their qualifications follows. In addition to reviewing materials from the PIs sent prior to the meeting, each Review Panel member spent two and a half 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.

Review Panelists

John R. Benemann, Ph.D.

- Consultant
- 1993-2000: Assoc. Research Engineer, Dept of Civil Engineering and Plant Microbial Biology, University of California at Berkeley
- Focus: Biomass Energy; Environmental Biotechnology; Greenhouse Gas Mitigation; and Microalgae
- Located: Walnut Creek, CA

Garry Brewer, Ph.D

- Weyerhauser Chair, Joint Forestry and School of Management, Yale
- Previously member of the President's Nuclear Waste Technical Review Board
- Previously Dean, School of Environmental Sciences, University of Michigan
- Founding member Swedish National Environmental Research Foundation and King Carl XVI Gustaf Professor of Environmental Sciences
- Focus: Economic and management implications of environmental strategies
- Located: Hew Haven, CT

Robert C. Burruss, Ph.D

- Project Chief Assessment of Geological Reservoirs for Carbon Dioxide Sequestration, U.S. Geological Survey
- Project Scientist, North Alaska Petroleum Evaluations;
- Previously, Geochemistry Scientist, Gulf Oil Corporation
- Focus: Assessment of Repositories for Geologic Sequestration of CO_2
- Located: Reston, VA.

John F. Clarke, D.Sc.

- Deputy Director, Office of National Labs in Science and Technology, Department of Homeland Security (DHS).
- Previously: Joint Global Change Research Institute, University of Maryland, and DOE Associate Director of Energy Research and Executive Director of DOE Climate Activities.
- Focus: application of conditional choice theory to the market competition of energy technologies in macro-economic models
- Located: Washington, DC

Bruce Reynolds

- Department Manager Fossil Energy Technology, Idaho National Laboratory
- Fossil Energy Technology Department has responsibility for all aspects of oil and natural gas exploration and production, coal, hydrogen and methane hydrates.
- Broad background in environmental management, R&D and technology transfer
- Located: Idaho Falls, ID

Ruben Simoyi, Ph.D.

- Professor, Department of Chemistry, Portland State University
- American Society of Chemistry, American Physical Society, & Royal Society of Chemistry
- Extensive experience in computer modeling and mathematics related to chemistry
- Located: Portland, OR

David Thomas, Ph.D.

- Consultant
- Previously, 24 years with BP Amoco Corporation, including Manager, CO_2 Mitigation Technology, Green Operations
- Focus: CO_2 mitigation technology and related policy issues
- Located: Naperville, IL

Raymond L. Zahradnik, Ph.D.

- Consultant and Partner in Appalachian-Pacific LLC
- Previously, Professor of Chemical Engineering, Carnegie-Mellon University
- Previously, Director of Coal Conversion and Utilization, Energy Research and Development Administration (ERDA)
- Previously, Director of Energy Research for Occidental Petroleum Corp and President of Occidental Oil Shale, Inc.
- Focus: Clean Coal Technology
- Located: Steamboat Springs, CO

APPENDIX D
Reviewer Evaluation Sheet

At the Project Review meeting, the panel of reviewers was asked to comment on the projects presented in a number of ways. Following is a brief description about how the project evaluation was done.

Evaluation Criteria

The ASME team, in cooperation with the DOE Project Manager and the WVU National Research Center for Coal and Energy (NRCCE), developed a set of 10 evaluation review criteria to be applied to each project. They were defined as follows:

Project Merit:

1: Scientific and Technical Merit
- The underlying project concept is scientifically sound.
- Substantial progress or even a breakthrough is possible.
- A truly innovative approach to long-term CO_2 disposal and storage.

2: Anticipated Benefits if Successful
- A clear statement of potential benefits if research is successful.
- Potential emissions reduction through sequestration is substantial.
- There are possible collateral benefits or by-products.

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 DOE ultimate sequestration cost goals.

7: 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.
- This project is likely to be implemented if research is successful.
- Barriers to commercialization have been considered.

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 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.

Evaluation

Reviewers were asked to consider these definitions carefully in assessing the progress and achievements of each project presented and then develop an evaluation rating for each criterion based on his/her own best judgment. Possible evaluations were divided into three discrete categories: Meets Expectations, Exceeds Expectations, or Does Not Meet Expectations.

These Evaluation Criteria were also provided to all of the project teams as part of their instructions for preparing for the meeting. This seems to have had a positive effect as many of the teams commented that they might not have addressed one or more of these topics had they not been told ahead of time that the project team would be evaluated based on these 10 criteria.

A blank copy of the Reviewer Evaluation Sheet follows.

REVIEWER EVALUATION SHEET

Project Code_____ Principal Investigator(s)_____

Reviewer_____

Criterion:	**Does Not Meet Expectations***	**Meets Expectations**	**Exceeds Expectations**
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			

* Note: If you ranked any of the above criterion as "Does Not Meet Expectations," please explain why in the space provided on the reverse side.

1. **Strengths** _____

   _____

   _____

   _____

2. **Weaknesses** _____

   _____

   _____

   _____

3. **Recommendations** _____

   _____

   _____

   _____

4. **Action Items** _____

   _____

   _____

   _____

5. **General Comments** _____

   _____

   _____

6. **Why this project "Does Not Meet Expectations"** _____

   _____

   _____

   _____

Project Code _____ **Reviewer Name:**_____

APPENDIX E
Project Summaries

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number **OST-14-06**	**Project Title: Novel CO_2 Capture Concept**		
Contacts DOE/NETL Project Mgr.	**Name** Jose D. Figueroa	**Organization** DOE/NETL	**E-mail** jose.figueroa@netl.doe.gov
Principal Investigator	Robert Dilmore, Ph.D., P.E.		
Partners	Yee Soong, Sheila Hedges, Craig Griffin – NETL, Pittsburgh		
	Mohammed Ataai, Richard Koepsel – University of Pittsburgh Biotechnology Center		
Stage of development	**X** Basic R&D __Applied R&D __Proof of Concept __Demonstration		

Technical Background:
The process, as envisioned, employs the enzyme carbonic anhydrase to catalyze the absorption of CO_2 into aqueous solutions that are buffered with polyacrylamide beads with copolymerized acrylamido buffering monomers of known pK. The enzyme CA, ubiquitous in nature, is capable of catalyzing the hydration of CO_2 as much as 10^6-fold, and is resilient over a relatively wide range of environmental conditions. The polyacrylaminde buffering monomers under consideration are commonly used in the electrophoretic technique known as isoelectric focusing and have incorporated tertiary amines that provide the protolytic moiety used in CO_2 capture.

Relationship to NETL Carbon Sequestration Program:
This research project is an advanced biological approach seeking to integrate naturally-occurring phenomena into a CO_2 capture process. It contributes to the U.S. DOE Office of Fossil Energy's Carbon Sequestration Core Program focus on novel carbon capture concepts, with potential to lower the capital cost and energy penalty associated with capturing CO_2 from large point sources.

Primary Project Goal: The primary goal of this research project is to identify a simple and cost-effective process employing the enzyme carbonic anhydrase to facilitate CO_2 capture.

Objectives :

- Alter polyacrylamide buffer bead (PABB) recipe to increase overall CO_2-bearing capacity (target of 3 moles per kg dry bead or better)
- Evaluate PABB for application in repeated CO_2 absorption and regeneration over many cycles
- Consider alternative CO_2 sorbents that can be immersed in water and retain CO_2-bearing capacity
- Verify the activity and resilience of CA and immobilized CA samples provide by University of Pittsburgh researchers over repeated loadings
- Evaluate the kinetics of HCO_3/bead interaction and heat of reaction to determine water recycle rate
- Develop a bench-scale apparatus (small volume) to evaluate the process concept using CO_2 balanced in nitrogen gas and simulated flue gas
- Develop a first approximation of process cost for use as a decision point for allocation of future research funds

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number **DE-FG26-04NT42120**	**Project Title: Novel Dual-Functional Membrane for Controlling Carbon Dioxide Emissions from Fossil Fuel Power Plants**		
Contacts DOE/NETL Project Mgr	**Name** Jose D. Figueroa	**Organization** DOE/NETL	**E-mail** jose.figueroa@netl.doe.gov
Principal Investigator	C. Jeffrey Brinker University of New Mexico cjbrink@sandia.gov		
Partners	George Xomeritakis University of New Mexico xomerita@unm.edu		
	Andy Tsai T3 Scientific andy.tsai@t3sci.com		
Stage of development	__Basic R&D **X** Applied R&D __Proof of Concept __Demonstration		

Technical Background:
Microporous silica membranes derived by sol-gel processing (Fig. 1) show size-based molecular sieving behavior for permeation of permanent gases (Fig. 2) as a result of differences in diffusion rates through the ultramicropores of the inorganic porous network. The novel feature of this project is to introduce amine-functional groups in the microporous silica network (Fig. 3) in order to enhance the membrane affinity for CO_2 and block permeation of gases present in flue gas, e.g. N2, O2 and SO2 (Fig. 4) In this way, the new membrane is expected to exhibit higher CO_2 selectivity compared to prior, purely siliceous membranes that perform separations based on difference in molecular size only. The membrane will be deposited on porous ceramic tubular and hollow fiber supports by sol-gel dip-coating (Fig. 5) and is expected to have a multilayer asymmetric structure (Fig. 6) consisting of a thin (<100 nm) microporous gas separation layer (pore size 4-10 Å) on top of an intermediate mesoporous (pore size 15-50 Å) sublayer derived by surfactant-assisted self-assembly and conventional sol-gel processing.

Relationship to NETL Carbon Sequestration Program:
CO_2 capture

Primary Project Goal:
The overall objective of this project is to develop a new type of membrane capable of removing carbon dioxide emissions from coal-fired power plants efficiently and inexpensively and to produce fundamental data on the capacity of the new membrane. The fundamental data obtained will be used to estimate the impact (including capital and operating costs) of using the membrane in a full-scale system to remove carbon dioxide from flue gas in a pilot scale facility at the National Energy Technology Laboratory should the technology prove to be viable during proof of concept research at the University of New Mexico and T3 Scientific.

Objectives:
• Prepare and characterize (amine-functional) silica membrane materials with a CO_2:N2 selectivity >50 and a CO_2 permeance >2.0 cm3(STP)·cm-2·min-1·atm-1 at 100-130ºC and 10-20% feed relative humidity.
• Conduct small-scale parametric testing, using a simulated multicomponent gas, to determine optimum performance conditions.
• Optimize thin membrane deposition.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number NT42122	**Project Title: Design and Evaluation of Ionic Liquids as Novel CO_2 Absorbents**		
Contacts DOE/NETL Project Mgr	**Name** Jose D. Figueroa	**Organization** DOE/NETL	**E-mail** jose.figueroa@netl.doe.gov
Principal Investigator	Edward Maginn	University of Notre Dame	ed@nd.edu
Partners	Joan Brennecke	University of Notre Dame	jtb@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 that 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 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 percent 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 liquid for testing
- Carry out physical property screening measurements of 1st 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 candidates compounds
- Carry out heat capacity, thermal decomposition and viscosity measurements
- Write final report, and assess path forward

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number DE-FG2604NT42119	**Project Title: A New Concept for the Fabrication of Hydrogen Selective Silica Membranes**
Contacts: DOE/NETL Project Mgr	Name Organization E-Mail David Lang NETL lang@netl.doe.gov
Principal Investigator	Michael Tsapatsis
Partners	None
Stage of Development	**X** Basic R&D __Applied R&D __Proof of Concept __Demonstration

Technical Background:
A simple novel method for the fabrication of H2-selective silica membranes is investigated. It represents a drastic departure from the other approaches that are currently pursued worldwide. Our approach relies on the use of layered building blocks (tiles) that have very small pores and are expected to be H2-selective in the direction perpendicular to the tile surface. The tiles have well-defined "crystalline" structures consisting of a majority of interconnected SiO4 tetrahedra and a relatively small number of terminal Si-OH surface groups. Our objective is to use the silicate tiles as building blocks for the formation of extremely thin, H2-selective, highly ordered SiO2 coatings. We employ layer-by-layer depositions followed by high temperature calcination. We concentrate on a family of layered silicates that are precursors to high silica zeolite structures.

Relationship to NETL Carbon Sequestration Program:
Integrated Gasification Combined Cycle (IGCC) with membrane reactor water gas shift (WGS) reaction is a feasible and desirable option for CO_2 emission control (80 percent CO_2 recovery) for coal derived energy. At least 80 percent reduction of CO_2 emissions from coal-fuelled power plants will be accomplished by the proposed technology resulting in residual carbon dioxide emissions of 0.1 $KgCO_2$/kWhr.

Primary Project Goal:
The primary goal of the proposed research is to develop a new method for the fabrication of high temperature hydrogen selective silica membranes. The method consists of synthesis of ordered layered silicates, preparation of thin plate-like particles from these layered silicates and deposition of the particles using layer-by-layer assembly followed by calcination. The membranes will be tested for hydrogen separation from carbon dioxide at high temperature and pressure and for hydrothermal stability.

Objectives: Synthesis of layered silicates and optimization of thin plate-like particle morphology. Particle dispersion in water and organic solvents containing matrix precursors. Preparation of coatings of the plate-like particles and connecting matrix material. Coating microstructural characterization to ensure particle orientation and good coverage. Determination of membrane separation performance. Determination of membrane stability in a water gas shift environment. Selection of most promising membrane material for further development. Target is H2/CO_2 selectivity of 100 and H2 flux of 0.1mol/m2-s at 1 atm pressure difference.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number FWP49539	**Project Title: CO_2 Capture for PC-Boiler Using Flue-Gas Recirculation: Evaluation of CO_2 Capture / Utilization / Disposal Options**

Contacts:	**Name**	**Organization**	**E-Mail**
DOE/NETL Project Mgr	Timothy Fout	NETL, Morgantown	Timothy.Fout@NETL.DOE.GOV
Principal Investigator	Richard D. Doctor	Argonne National Laboratory	rdoctor@anl.gov
Partners	None		
Stage of Development	__Basic R&D **X** Applied R&D __Proof of Concept __Demonstration		

Technical Background:
CO_2 for sequestration using oxygen-fired combustion with flue gas recycle to maintain a normal temperature profile in the furnace is being studied as a Carbon-Capture strategy. The product directly leaving the boiler then is a CO_2-rich stream that is ready for sequestration or use with only modest conditioning. Conditioning is required to dry the CO_2, remove oxygen to prevent corrosion in the pipeline, and possibly other contaminants and diluents such as nitrogen, SO_2 and NOx. This approach was conceived in the early 1980s at Argonne National Laboratory (ANL) as a low-cost CO_2 source for enhanced oil recovery (EOR). A molar ratio of CO_2/O_2 of about three is necessary to preserve the heat transfer performance and gas path temperatures, allowing this system to be applied as a retrofit. ANL is studying all the engineering aspects of this system, including the effect of impurities, such as SO_2 and NOx, and CO_2 transportation, use, and options for long-term sequestration. If the flue gas can be recycled before SO_2 scrubbing, significant cost savings are possible.

Relationship to NETL Carbon Sequestration Program:
CO_2 Capture including Transportation and Sequestration

Primary Project Goal:
This project will provide the power industry with a low-cost retrofit system that could remain in service during future upgrades at the power plant. The captured CO_2 can be used for EOR or sequestered. Overall, this project addresses both design and full energy-cycle issues pertaining to our current coal-fired power plants.

Objectives:
During this current year, efforts will focus on the advantages for flue gas recirculation as a CO_2 capture option. The full energy cycle will be considered, including mining, coal transportation, coal preparation, the PC-fired boiler with power generation, particulate removal and flue-gas recirculation, pipeline CO_2 conditioning, and pipeline transport of CO_2 to sequestration. For the reservoir modeling, we will continue to develop a new computational scheme for the derivative computation of the reaction kinetics model of the code. Then, the inverse modeling code of the CHEM-TOUGH2 model generated by the AD method will provide the tools for developing an optimal CO_2 flow management scheme with a reaction model or mineral sequestration process.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number **NT42430**	**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 Organization E-Mail** Timothy Fout, National Energy Technology Laboratory, Timothy.Fout@netl.doe.gov
Principal Investigator	Thomas K. Gale, Env. & Energy Dept., Southern Research Institute, Gale@SRI.ORG
Partners	Curtis Taylor, MAXON Corporation, ctaylor@maxoncorp.com
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	Kevin Davis, Reaction Engineering International, davis@reaction-eng.com
Stage of Development	__Basic R&D __Applied R&D __Proof of Concept _**X**_Demonstration

Technical Background:

Oxy-enhanced combustion has been pursued for several years by industries and oxygen suppliers for the purpose of increasing process production, energy efficiency, and reducing NOx emissions. To date however, only limited experience with oxygen-fired CO_2 recycle has been obtained. 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. However, the tests were limited to proof of concept. To date, the data available for developing a relationship between the adjustable parameters for oxy-fired CO_2-recycle and NOx emissions, unburned carbon in the ash, efficiency improvements, flame stability, heat flux, and boiler temperatures has been limited.

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 NOx 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 reduce NOx formation.

A full-scale retrofit of a Turbo Oxy Cycle power plant has been performed, resulting in 98 percent 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-cofiring project, a detailed understanding of the relationship between NOx emissions and biomass/coal cofiring was obtained for a wide range of operating conditions. Parameters examined included various means of cofiring the biomass (blended, co-milled, separate injection (in-flame and post flame)), staging the air (including use of low-NOx 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 NOx 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 percent 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 bring oxy-fired CO_2 recycle from proof of concept to full-scale demonstration, 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.

Finally, 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, stoichometry, coal type, slaging, furnace exit oxygen, and fuel processing.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number **LBL-6-G204**	**Project Title: The GEO-SEQ Project**
Contacts: DOE/NETL Project Mgr	**Name** **Organization** **E-Mail** Lynn Brickett NETL lynn.brickett@netl.doe.gov
Principal Investigator	Dr. Sally M. Benson, Lawrence Berkeley National Laboratory
Partners	Dr. Peter Cook, Chief Executive, CO2CRC, Australia
	Mr. Iain Wright, In Salah Monitoring Joint Industry Project Director, BP
	Dr. Susan Hovorka, University of Texas, Austin
Stage of Development	__Basic R&D _**X**_Applied R&D __Proof of Concept __Demonstration

Technical Background:

The GEO-SEQ Project has two primary goals: 1) to develop simple field tests that can be used to improve predictions of injectivity and capacity of saline formations and depleted gas reservoirs and 2) to develop and test innovative high-resolution methods for monitoring CO_2 in the subsurface. This will be accomplished by carrying out field tests in three very different geological environments, including the Frio Formation in Texas, the Waare Formation in the Otway Basin in Australia, and In Salah Gas Field in the Ahnet-Timinoun Basin in Algeria. The GEO-SEQ Project leverages large investments by other governments and industry in field testing, particularly at the Otway Basin Pilot Project and the In Salah Gas Project. The diversity of geological environments spans a wide range of formation types relevant to geological storage in the United States. Participation in these projects provides a unique opportunity to develop and test new methods for field testing, from pilot-scale tests up to a commercial scale project.

Core capabilities of the project team in the Earth Sciences Division at Lawrence Berkeley National Laboratory include:

• Instrument development and fabrication for real-time acquisition of seismic data, fluid samples and pressure data (e.g. Freifeld et al., 2006);
• Model development, including the extensively used TOUGH2, TOUGH-REACT, ITOUGH, and TOUGH-FLAC codes (e.g. Pruess, 2005);
• Forward and inverse geophysical simulators for predicting and interpreting seismic, EM, pressure and gravity data (e.g. Daley et al., 2006);
• Experience deploying complex instrument packages for CO_2 injection projects (e.g. Hovorka et al., 2006); and
• Joint inversion and interpretation of multi-disciplinary data sets (e.g. Doughty, 2006).

These capabilities will be used to design and interpret test data, with the overall goals of developing reliable methods for predicting injectivity and storage capacity and developing innovative high-resolution methods for monitoring CO_2 migration in the subsurface.

Task 1 – Phase II for the Frio Brine Formation Pilot Tests
Task 2 – Deploy and evaluate MMV and simulation technologies at the Otway Basin Pilot Project in Australia
Task 3 – In the Salah Pilot Test, use MMV techniques to evaluate the injectivity and geomechanical response at the In Salah Gas Project in Algeria

Relationship to NETL Carbon Sequestration Program:
The GEO-SEQ Program relates to two of the five goals of the core research program, namely 1) Carbon Storage and 2) Measurement, Mitigation and Monitoring (MMV). In the Storage Program, GEO-SEQ directly supports the 2007 metric of conducting field tests to improve the understanding of the factors affecting capacity in a broad range of formation and the 2012 metric to demonstrate the ability to predict storage capacity with $\pm$30 percent accuracy. In the MMV Program, GEO-SEQ directly supports the 2007 metric to demonstrate advanced CO_2 measurement and detection technologies at sequestration field tests and commercial deployments, and the 2012 metric of MMV protocols to enable 99 percent of stored CO_2 to be credited as net emissions reduction.

Objectives:

Task 1: Phase II of the Frio Brine Formation Pilot Tests

1a. Develop a continuous real-time cross-well seismic data acquisition system for deploying during the Frio II Test.
1b. Develop an improved version of the U-tube sampling system that will allow more frequent sampling.
1c. Perform design studies using TOUGH2 to optimize our ability to observe capillary trapping and buoyancy drive flow.
1d. Successfully deploy the instruments described above to collect a high quality data set on CO_2 mitigation between injection and observation well.
1e. Interpret the test data using state-of-the-art models (e.g. TOUGH2, TOUGH-REACT)
1f. Enhance the analytical model for pressure buildup and injectivity to account for anisotrophy and partial penetration.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number **OST-14-06**	**Project Title: Adsorption Studies – Carbon Dioxide Storage in Coal Seams**
Contacts: DOE/NETL Project Mgr	**Name Organization E-Mail** Charles Byrer, NETL, Charles.Byrer@NETL.DOE.GOV
Principal Investigator	Angela Goodman, NETL, angela.goodman@netl.doe.gov
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	Industry Project Partners Pennsylvania State University Oklahoma State University TICORA Geosciences CSIRO, Australia Netherlands Institute of Applied Geoscience TNO University of British Columbia, Canada Aachen University, Germany
Stage of Development	_**X**_Basic R&D _**X**_Applied R&D __Proof of Concept __Demonstration

Technical Background:
Four tasks address the storage capacity of coal seams and the trapping mechanism in which CO_2 is stored in the coal seam:
- Task 1: Inter-laboratory comparison of CO_2 adsorption isotherms
- Task 2: Infrared study of CO_2 sorption on coal
- Task 3: Dilatometry and manipulation of coal sorption capacity by CO_2 pressure cycling
- Task 4: Gravimetric-volumetric method of measurement of CO_2 adsorption on coal

Relationship to NETL Carbon Sequestration Program:
This project is tied to the "Carbon Sequestration Technology Roadmap and Program Plan - 2005" under Table 1, Top-level Carbon Sequestration Roadmap. This project will help meet the goal of demonstrating the ability to predict CO_2 storage capacity with +/-30 percent accuracy by 2012. This work is also linked to Sequestration/Storage goals listed in Table 5 where the capability to predict CO_2 storage capacity" and injection techniques to enhance CO_2 contact with coal seam" will be investigated. Specifically the project will address the trapping mechanism and storage capacity for CO_2 storage in coals seams. The project will also provide insight into how coal swelling may restrict flow of CO_2 into coal seams and cause geological stability problems.

Primary Project Goal:
The project will address the trapping mechanism and storage capacity for CO_2 storage in coals seams. The project will also provide insight into how coal swelling may restrict flow of CO_2 into coal seams.

Objectives:

- Task 1: To ensure information obtained from laboratory-measured sorption isotherms will be useful for assessing the technical feasibility of CO_2 sequestration in coal-seams. The data obtained in the project could also provide the basis for an ASTM or ASTM-like laboratory method when coal seam sequestration becomes commercial.
- Task 2: To address the CO_2-coal storage capacity at pressures up to 15 MPa and better understand the CO_2-coal trapping mechanism
- Task 3: To understand softening and swelling of coal under conditions relevant to carbon sequestration
- Task 4: To obtain information for accurate estimates of CO_2 sorption by coal and to develop a model to generate adsorption isotherms via numerical techniques established for data analysis.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

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** **Organization** **E-Mail** William O'Dowd U.S. DOE/NETL ODOWD@NETL.DOE.GOV
Principal Investigator	Robert E. Douglas CONSOL Energy Inc. bobdouglas@cnxgas.com
Partners	
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 (and eventual sequestration) 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 will be 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 2006.

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; also drill wells 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 coal seam during injection and the impact of the injection on CBM production; and monitor the behavior of the sequestered CO_2.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number NT42212	**Project Title: Low Cost Open-Path for Monitoring Atmospheric Carbon Dioxide at Sequestration**
Contacts DOE/NETL Project Mgr.	**Name** Jose D. Figueroa **Organization** DOE/NETL **E-mail** jose.figueroa@netl.doe.gov
Principal Investigator	William A. Goddard III California Institute of Technology wag@wag.caltech.edu Sheng Wu Peer Center, Caltech sheng@peer.caltech.edu
Partners	
Stage of development	__Basic R&D **X** Applied R&D __Proof of Concept __Demonstration

Technical Background:

A CO_2 monitoring system that monitors CO_2 concentration covering large area and over long term is needed to verify the underground CO_2 sequestration processes.

This project uses a phase insensitive Two-Tone Frequency Modulation spectroscopy method that measures the CO_2 gas in the long open path. The technology is tailored toward long operation distance with minimal maintenances.

Relationship to NETL Carbon Sequestration Program:

This project falls into part 3 of "Core R&D" -- the Monitoring, Mitigation, and Verification (MM&V). It will provide a cost effective, wide area, CO_2 concentration monitoring and CO_2 sequestration verification method.

Primary Project Goal:

The overall objective of the work is to develop and test an open-path type instrument that will measure and monitor atmospheric carbon dioxide emissions from geological sequestration sites within a 300 to 500 ppmv range over 5km path length.

Objectives :

- The first objective is to develop a proof of concept instrument in the laboratory that measures CO_2 concentration and with special features that enable its operation for long range open path measurement as well.
- The second objective is to build the prototype that could operate over 100 meters and verify the open path operation capability of the instrument.
- The final objective is to build a prototype monitor will be capable of measuring the CO_2 concentration with an update speed of once every several minutes and over a five (5) kilometer path length with a 98 - 99 percent accuracy.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number FWP04FE04-06	**Project Title: CO_2-Water-Rock Interactions and the Integrity of Hydrodynamic Seals**
Contacts: DOE/NETL Project Mgr	**Name Organization E-Mail** David Lang; National Energy Technology Laboratory; David.Lang@netl.doe.gov
Principal Investigator	J. William Carey; Los Alamos National Laboratory; bcarey@lanl.gov
Partners	Michael Hirl; Kinder Morgan CO_2 Company, LP; Michael_Hirl@kindermorgan.com
Stage of Development	**X** Basic R&D __Applied R&D __Proof of Concept __Demonstration

Technical Background:
The early performance of a geological CO_2 sequestration reservoir depends critically on hydrodynamic trapping of the buoyant CO_2 plume. The hydrodynamic seals include an impermeable caprock and the Portland cement used in wellbores that penetrate the reservoir. Simple calculations based on the thickness and permeability of caprock and Portland cement demonstrate that, in the absence of defects or CO_2-induced changes to these seals, geologic reservoirs can store CO_2 for geologic periods of time. Indeed, the widespread occurrence of oil and gas reservoirs (as well as natural CO_2 reservoirs) shows that natural systems are well suited for the storage of CO_2. As a consequence, the key performance issues for hydrodynamic seals center on the possibility of CO_2-induced degradation and the existence and behavior of defects. Portland cement is of particular concern because it is known to be reactive with CO_2-bearing fluids. However, the consequences of CO_2-interaction with Portland cement and with defects in the caprock are a complicated function of the geochemical and hydrologic environment surrounding the wellbore and the caprock/reservoir interface. Our approach has been to use field observations to develop an understanding of this environment and then use the resulting conceptual model to design experimental studies and numerical models of reservoir containment of CO_2.

Relationship to NETL Carbon Sequestration Program:
This research project directly addresses the "Primary objectives [of] … (2) improving understanding of factors affecting CO_2 storage permanence… and safety in geologic formations…" given by NETL as "Core research and development" on their Carbon Sequestration web site.

Primary Project Goal:
Develop a fundamental understanding of how CO_2-water interactions enhance or degrade the integrity of hydrodynamic seals. Ultimately, we seek to develop numerical models of CO_2 leakage.

Objectives:
1. Obtain core samples from CO_2-sequestration analog including CO_2 enhanced oil recovery reservoirs and natural CO_2 reservoirs.
2. Fully characterize samples and evaluate for evidence of CO_2 migration from the reservoir.
3. Formulate conceptual model of CO_2 leakage mechanisms.
4. Conduct experimental studies of CO_2 interaction with hydrodynamic seals.
5. Develop numerical models of CO_2 reaction with hydrodynamic seals.
6. Determine whether CO_2-leakage rates evolve with time due to either dissolution and widening of leakage pathways or precipitation and closure of leakage pathways.
7. Refine experimental and numerical studies to develop predictions of CO_2 leakage.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number **DE-FC26-05NT42431**	**Project Title: Strategies to Optimize Microbially-Mediated Mitigation of Greenhouse Gas Emissions from Landfill Cover Soils**
Contacts DOE/NETL Project Mgr.	Charles Bryer, National Energy Technology Laboratory CHARLES.BYRER@NETL.DOE.GOV
Principal Investigator	Jeremy D. Semrau, The University of Michigan, jsemrau@umich.edu
Partner	Michael J. Barcelona, Western Michigan University, michael.barcelona@wmich.edu
Stage of Development	**X** Basic R&D __Applied R&D __Proof of Concept __Demonstration

Technical Background:
In the proposed research, a combination of laboratory and field experiments will be coupled to provide integrated assessment and treatment technologies to mitigate greenhouse gas emissions from landfill cover soils. Specifically, it has been often reported that two major greenhouse gases, methane and nitrous oxide, are inversely related and methodologies that reduce the emission of one cause the other to be enhanced. Such an inverse relationship is due to the complex microbial mechanisms that generate methane and nitrous oxide. To develop holistic, effective, and economic treatment procedures, one must be aware of what geochemical parameters affect the pertinent microbial populations and how these parameters can be effectively manipulated to maximize microbial consumption of methane while simultaneously minimizing microbial production of nitrous oxide. To that end, a range of geochemical parameters known to affect biogenic greenhouse gas production and consumption will be examined and a combination of kinetic (i.e., methane and nitrous oxide oxidation/emission) measurements coupled with microbial community characterization and quantification of gene expression and activity, will be used to better determine how to minimize the overall impact of greenhouse gas emissions from landfills.

Relationship to NETL Carbon Sequestration Program:
Non-CO_2 Greenhouse Gas Control

Primary Project Goal:
The overall goal of this proposal is to determine how to best stimulate microbial activity *in situ* to achieve minimal greenhouse gas emission, particularly in landfill cover soils.

Objectives:
In the first phase of the research, a matrix of soil microcosms will be constructed with landfill cover soils and exposed to geochemical parameters that are known to affect methane and nitrous oxide consumption and production, respectively, by well-defined laboratory cultures. These include water content, available copper, nitrogen source and amount, oxygen mixing ratios, and selective inhibitors for the cells responsible for greenhouse gas production. From these studies, we will determine what combination of these parameters can promote microbial removal of methane while minimizing nitrous oxide production. In the second phase, we will show *in situ* how net greenhouse gas emissions can be reduced using both passive and active treatment application strategies that create and maintain optimal geochemical conditions.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number **DE-FC26-05NT42433**	**Project Title: Bio-Tarp: Reducing Landfill Methane Emissions with Bioactive Alternative Daily Cover**
Contacts DOE/NETL Project Mgr	Name Organization E-Mail Charles Byrer DOE-NETL Charles.Byrer@netl.doe.gov
Principal Investigator	Helene Hilger, PhD, Assoc. Prof, Civil Engineering, UNC Charlotte, Charlotte, NC hhilger@uncc.edu
Partners	James Oliver, PhD, Prof, Biology, UNC Charlotte, Charlotte, NC jdoliver@uncc.edu
	Jean Bogner, PhD, Founder, Landfills, Inc., Wheaton, IL
	David Jones, Product Development, Ten Cate Nicolon, Pendergrass, GA
Stage of Development	__Basic R&D _**X**_Applied R&D __Proof of Concept __Demonstration

Technical Background:
Methane is produced when landfill bacteria degrade organics in the waste. As such, landfills are the largest source of anthropogenic methane emissions in the United States. Federal efforts to mitigate methane emissions after landfill closure are being implemented, but by this time, a significant portion of methane has already leaked into the atmosphere. Methane production can begin soon after waste placement, and as much as several hundred g CH4/m-2d-1 were measured in emissions from an open active cell. There is a group of bacteria, the methanotrophs, that is ubiquitous in the environment and that occur in large number in soil landfill covers. They are aerobes, oxidizing methane to carbon dioxide and water, and they have been well-studied for their potential to mitigate landfill methane emissions. All open cells must be covered at the end of each working day (Substitle D, Resource Conservation and Recovery Act). Most landfills use a 6-in soil layer; however, many use a tarp or foam spray instead to reduce cost and save valuable fill space. The thrust of this research effort is to design a tarp matrix impregnated with immobilized methane oxidizing bacteria and then field test it for use as a daily cover that will reduce methane emissions during the active life of a landfill.

Relationship to NETL
Carbon Sequestration Program: Non-CO_2 Greenhouse Gas Control Molecule-for-molecule, methane is over 20x more potent at trapping heat than is carbon dioxide. Since landfills are the largest source of anthropogenic methane emissions in the United States, targeting landfill methane emissions reduction makes sense. Since much of the methane can escape before a landfill is capped, this project focuses on reducing those early releases.

Primary Project Goal: The goal of this research is to design a tarp matrix impregnated with immobilized methane oxidizing bacteria and then field test it for use as a daily cover that will reduce methane emissions during the active life of a landfill.

Objectives: Three major research objectives were identified: The first objective was to test several suitable bacteria immobilization techniques to identify the best method(s) for tarp design. The best methods are those that permit sustained, robust methane oxidation activity and lend themselves to satisfactory incorporation into a tarp matrix. Attachment, embedding and encapsulation were identified as promising methods. The second objective is to identify suitable tarp materials and designs, where the optimum design allows integration of cells into a reusable tarp material that will permit gas diffusion, conserve moisture, and generally promote good biotic activity, as well as perform all of the other more typical functions desired from Alternative daily cover on an active landfill cell. Geotextile, natural

sponge, glass beads, polymer membranes, and plastic trickling filter supports were targeted as likely to be successful. The third objective is to produce some feasible prototype biotarps for field testing and test them in triplicate over the course of one year. Based on the results, a final prototype design will be recommended.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number **DE-FC26-05NT42437**	**Project Title: Application of Low-Cost Digital Elevation Models to Detect Change in Forest Carbon Sequestration Projects**
Contacts DOE/NETL Project Mgr.	**Name** **Organization** **E-Mail** John Litynski DOE/NETL John.Litynski@netl.doe.gov
Principal Investigator	Kenneth MacDicken, Winrock International, kmacdicken@winrock.org
Partners	Gary Kaster, American Electric Power, gkaster@hughes.net
Stage of Development	__Basic R&D **X** Applied R&D __Proof of Concept __Demonstration

Technical Background:
Monitoring of forest carbon stock change is an essential part of most active or envisioned carbon crediting systems. There is a continuing interest by project sponsors, proponents, implementers and regulators in reducing the cost of monitoring while improving accuracy and precision. The approach taken in this project is to test a combination of passive and active airborne sensing methods to create digital elevation models that can be used to assess carbon stock change at the stand level. A new 5-beam laser rangefinder array, two software packages to produce Digital Elevation Models (ERDAS and Terrest), and automated crown delineation methods are used to evaluate accuracy, precision and cost compared to conventional ground and aerial digital methods.

Relationship to NETL Carbon Sequestration Program:
The Monitoring, Mitigation and Verification terrestrial ecosystems research area seeks to develop automated technologies that offer lower cost, more detailed and timely information to be used in MM&V. This project is directly involved in producing, testing, and evaluating lower cost alternatives to ground and digital aerial methods now in use while maintaining predictable levels of accuracy.

Primary Project Goal:
The goal of this project is to reduce monitoring and verification costs in terrestrial sequestration by improving methods of estimating standing biomass in forests.

Objectives: The overall objective is to develop, test, and apply new low-cost technologies using 3D terrain models constructed using data from multiple ranging lasers and multispectral imagery to detect carbon stock changes in mixed hardwood forests. The application cost of each technology will be evaluated. Three systems will be compared: (1). Aerial digital imagery incorporating a new five beam laser rangefinder that will be used to produce high resolution DEM for calculation of carbon stock change between two time periods (2). Aerial digital imagery using automated tree crown delineation software and ArcInfo macros to calculate stocks based on 2006 imagery. (3). Ground plot methods using data to be collected and analyzed by project partner AEP for selected field sites in Ohio.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number **DE-FC26-05NT42432**	**Project Title: Intelligent Bioreactor Management Information System (IBM-IS) for Mitigation of Greenhouse Gas Emissions and Carbon Sequestration**
Contacts DOE/NETL Project Mgr.	**Name** **Organization** **E-mail** Heino Beckert DOE/NETL heino.beckert@netl.doe.gov
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	Don Augenstein, Institute for Environmental Management, Inc. (IEM) Palo Alto, CA
	Dr. Harold Bentley, Hydro Geo Chem Inc., Tucson, AZ
	Dr. Pei Chiu, Dept. of Civil and Environmental Engineering, University of Delaware, Newark, DE
Stage of development	__Basic R&D **X** Applied R&D __Proof of Concept __Demonstration

Technical Background:

Methane is an important contributor to global warming with a total climate forcing estimated to be close to 20 percent that of carbon dioxide (CO_2) over the past two decades. The largest anthropogenic source of methane in the United States is "conventional" landfills, which account for over 30 percent of the anthropogenic emissions. One means of mitigating methane emissions is to operate landfills as "controlled landfills" or "bioreactors." Here, biological conditions in the waste are optimized allowing more rapid and complete waste decomposition. In "anaerobic bioreactors," methane generation is enhanced through liquid addition. High efficiency capture of methane is utilized to maximize fuel energy recovery and minimize fugitive emissions. In "aerobic bioreactors," air and liquid are introduced in the landfill and the combined effects of heat and oxygen inhibit methane formation. Both "controlled" landfill operations hold promise for mitigating fugitive methane emissions form landfills.

As described below under *Cost Targets and Benefits,* bioreactor landfilling might result in significant reductions in equivalent fossil at attractive costs. Given the promise of this technology, several bioreactor landfills have been constructed in the United States, although most are field-scale research landfills. While a few commercial bioreactor landfills have been built, the waste management industry has yet to embrace this technology because of lingering concerns about the capture of fugitive greenhouse gases, how to manage liquid additions to maintain optimal moisture content which avoids seeps from landfill sidewalls, and the potential for fires (aerobic bioreactor). The design and operation of bioreactor landfills remain ad hoc, with no established procedures to guide landfill operations.

Relationship to NETL Carbon Sequestration Program:

This project falls under *Non-CO_2 Greenhouse Gas Control*. This project will evaluate revolutionary changes in design and management of bioreactor landfills. Fugitive methane emissions will be significantly reduced over conventional landfilling, and collected methane will offset fossil CO_2 through energy generation.

Primary Project Goal:

To develop and demonstrate an Intelligent Bioreactor Management Information System (IBM-IS) that will allow long-term operation of bioreactor landfills to mitigate fugitive methane emissions and offset fossil CO_2 production through energy generation.

Objectives:
The overall goal of this work is to develop and demonstrate an Intelligent Bioreactor Management and Information System (IBM-IS) for control of landfill gas extraction, air injection, and liquid addition in bioreactor landfills. To achieve this overall goal, two objectives will be pursued. First, an IBM-IS will be developed and tested for mitigating fugitive methane emissions from a new anaerobic cell with a permeable cover. Second, an IBM-IS will be developed and tested for controlled injection of air with liquids to maintain optimal conditions for suppression of methane generation in an aerobic landfill cell. To achieve these two objectives, numerous subtasks will be conducted to advance our understanding of fluid flow and biodegradation processes in landfills, and to develop new numerical models for describing these processes.

DOE CARBON SEQUESTRATION PROJECT SUMMARY SHEET

Project Number NT42589	**Project Title: Midwest Regional Carbon Sequestration Partnership (MRCSP) - Phase II (**DOE Contract ***DE-FC26-05NT4258***9)
Contacts: DOE/NETL Project Mgr	**Name** Charles Byrer **Organization** NETL **E-Mail** Charles.Byrer@netl.doe.gov
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Stage of Development	__Basic R&D __Applied R&D _**X**_Proof of Concept __Demonstration

Technical Background: Carbon sequestration is the term used to describe a broad class of technologies for capturing and permanently sequestering, or storing, carbon dioxide (CO_2). Affordable and environmentally safe sequestration approaches could offer a way to help stabilize atmospheric levels of carbon dioxide. Ways to securely store CO_2 in biologic materials (terrestrial sequestration) or in deep underground formations (geologic sequestration) currently are being studied in the United States and around the world: Terrestrial sequestration involves carbon storage in soils, including degraded soils (soils that have declined in quality) and in forests and agricultural land. Geologic sequestration involves capturing and permanently injecting CO_2 into deep underground formations such as saline (saltwater) rock formations, depleted oil and gas fields, or unmineable coal seams. Scientists currently are testing these approaches on a small scale to determine how sequestration can provide a safe, effective, and efficient means of reducing atmospheric concentrations of CO_2. The Regional Partnership Program, established by the U.S. Department of Energy (DOE), is one of a number of components in DOE's overall program. It is designed to help answer some of these questions and to develop further knowledge regarding potential deployment of both terrestrial and geologic strategies for sequestration of CO_2. The MRCSP covers a seven-state region of Indiana, Kentucky, Maryland, Michigan, Ohio, Pennsylvania, and West Virginia.

Relationship to NETL Carbon Sequestration Program:
The Midwest Regional Carbon Sequestration Partnership (MRCSP) is one of seven partnerships in a nationwide effort to determine regionally-appropriate carbon sequestration options and opportunities. These partnerships are part of an overall effort by the U.S. Department of Energy's National Energy Technology Laboratory (DOE/NETL) to develop robust strategies for mitigating carbon dioxide emissions. The partnership is led by Battelle and includes over thirty organizations from the research community, energy industry, non-governmental organizations, and government.

Primary Project Goal:
The objective of the Phase II MRCSP is to test the safety and effectiveness of carbon sequestration and further add to understanding the best approaches to carbon sequestration in the region through a series of focused field tests of sequestration technologies. The overall approach for the MRCSP is to test a number of different sequestration options.

Objectives:
The Phase II effort focuses on conducting geological and terrestrial field testing projects at multiple locations to investigate carbon sequestration feasibility for the region. In addition, there are several ongoing tasks to refine geological framework, continue stakeholder outreach efforts, and encourage regulatory agencies to consider CO_2 sequestration options.