U.S. DOE CARBON STORAGE PROGRAM: 2015 PROJECT PEER REVIEW

Summary Report: 2015-TR2

October 2015

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ACKNOWLEDGEMENTS AND CITATIONS

This report describes research sponsored by IEAGHG. This report was prepared by:

James Craig, Samantha Neades and Tim Dixon

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The IEAGHG manager for this report was:
Tim Dixon

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Further information or copies of the report can be obtained by contacting IEAGHG at:

IEAGHG, Pure Offices, Cheltenham Office Park
Hatherley Lane, Cheltenham,
GLOS., GL50 6SH, UK
Tel: +44(0) 1242 802911
E-mail: mail@ieaghg.org
Internet: www.ieaghg.org

U.S. DOE Carbon Storage Program: 2015 Project Peer Review

Executive Summary

The U.S. Department of Energy (DOE), the Office of Fossil Energy, and the National Energy Technology Laboratory (NETL) are fully committed to improving the quality and results of their research projects. To support this goal, in fiscal year (FY) 2015, IEAGHG was invited to provide an independent, unbiased, and timely peer review of selected projects within the DOE Office of Fossil Energy's Carbon Storage Program. The peer review of selected projects within the Carbon Storage Program was designed to comply with requirements from the Office of Management and Budget.

Between March 2nd and 6th, IEAGHG convened a panel of five leading academic and industry experts to conduct a five-day peer review of 12 research projects from the NETL Carbon Storage Program. At the conclusion of each project review, these recognized technical experts provided recommendations on how to improve the management, performance, and overall results of each individual research project.

Members of the Expert Panel appointed by the IEAGHG were:

- Kevin Dodds, CCS M&V Technology Adviser, USA (Panel Chairman)
- Michael Kühn, GFZ German Research Centre for Geosciences, Germany
- Jonathan Ennis-King, CSIRO, Australia
- Randy Locke, Illinois State Geological Survey, USA
- Auli Niemi, University of Uppsala, Sweden

The panel was supported by Tim Dixon (Facilitator), James Craig and Samantha Neades, IEAGHG.

The Carbon Storage Program is focused on developing and advancing technologies that enable safe, cost-effective, permanent geologic storage of carbon dioxide (CO_2) both onshore and offshore in different depositional systems. The technologies being developed will benefit both industrial and power sector facilities that will need to mitigate future CO_2 emissions. The program also serves to increase understanding of the effectiveness of these advanced technologies and management approaches in different geologic reservoirs appropriate for CO_2 storage, and improve the ability to understand the behavior of CO_2 in the subsurface.

Core Storage Research and Development (R&D) is one of the three primary technology areas of the Carbon Storage Program. The selected projects included a variety of technical areas including: monitoring tool development; field testing for monitoring protocols; laboratory measurements; experimental and modeling; and two small-scale demonstration projects.

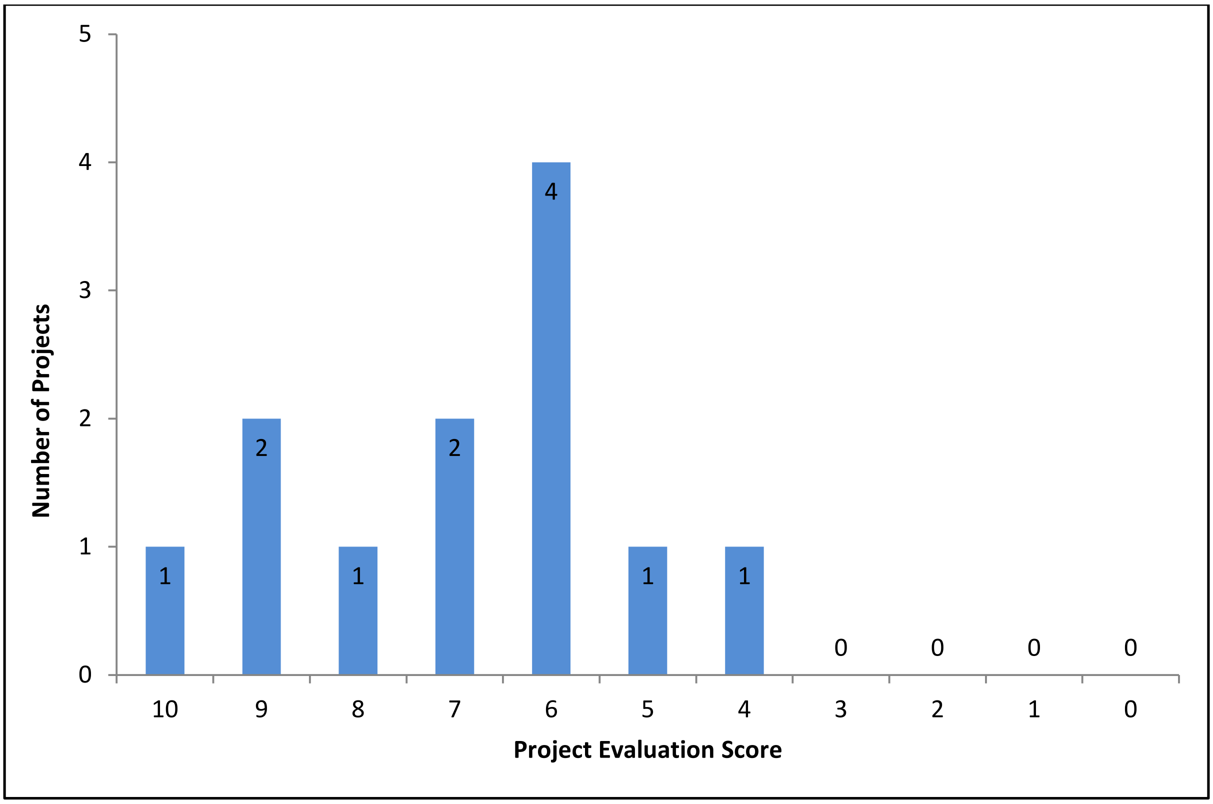
At the meeting, each research team made an uninterrupted 30 minute PowerPoint presentation. The final two experimental injection projects were allowed 45 minutes to present their results. In all cases the presentations were followed by a 30-minute question-and-answer session with the panel. The panel then held a 90-minute discussion and evaluation of each project. The time allotted for project presentations was dependent on the individual project's complexity, duration, and breadth of scope.

The panel discussed each project to identify and come to a consensus on each project's strengths, project weaknesses, and recommendations for project improvement. The panel designated all strengths and weaknesses as "major" or "minor" and ranked recommendations in priority order. The consensus strengths and weaknesses served as the basis for determining the overall project score in accordance with the Rating Definitions and Scoring Plan of the Peer Review Evaluation Criteria. The panel scored each project according to the following predetermined categories:

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

The individual overall ratings for the 12 projects range from 4 to 10. Nine received scores of between 6 and 9. There was a consensus view that the quality achieved by some projects was impressive, although some projects lacked focus on the DOE goals. The panel commented that these projects have challenging objectives and in some cases not all the projects managed to succeed in meeting their objectives. They also made a collective recommendation that many of the projects would benefit from proactive use of risk assessment methodologies to assist in the management of their objectives.

The overall scores for each project are summarised in the figure overleaf. It should be stressed that it is not the intention to compare different projects, the purpose of the chart is merely to provide a summary of the project scores.



Carbon Storage Peer Review Project Evaluation Scores

The panel concluded that the review provided an excellent opportunity to comment on the relative strengths and weaknesses of each project. The presentations have provided additional clarity which complemented the pre-meeting documentation. The review has also provided an insight into the range of technology development and the relative progress that has been made. The structure of the review, and the variety of different projects, has stimulated interest and engagement that should also be useful for the DOE program, especially the DOE project managers.

Contents

1 Introduction and Background

1.1 The Carbon Storage Program

The Carbon Storage Program is focused on developing and advancing technologies that enable safe, cost-effective, permanent geologic storage of carbon dioxide (CO_2) both onshore and offshore in different depositional systems. The technologies being developed will benefit both industrial and power sector facilities that will need to mitigate future CO_2 emissions. The program also serves to increase understanding of the effectiveness of these advanced technologies and management approaches in different geologic reservoirs appropriate for CO_2 storage, and improve the ability to understand the behavior of CO_2 in the subsurface. These advances in technology can assure the safe, cost-effective, permanent geologic storage of CO_2 and the establishment of a body of proven "Best Practices" to guide industrial pursuit for the development of storage sites in the variety of geologic formations that will be needed to support carbon capture and storage (CCS) in widespread commercial applications. The activities of the Carbon Storage Program directly support industry's ability to comply with regulations, as well as the regulatory community's confidence in technologies for reporting and compliance with guidelines.

The Carbon Storage Program is comprised of three primary technology areas (1) Core Storage Research and Development (R&D), (2) Storage Infrastructure, and (3) Strategic Program Support. These three areas work together to address significant technical challenges in order to meet program goals that support the scale-up and widespread deployment of CCS. Within these technology areas, emerging technologies are supported through applied laboratory- and pilot-scale research. In addition, promising technology options are being validated through small- and large-scale field projects. This approach allows technologies to develop from concept through validation in the field and increases the Nation's confidence in future safe, effective, and permanent geologic CO_2 storage.

The **Core Storage R&D** technology area focuses on CO_2-specific aspects of storage, including trapping mechanisms, plume tracking and stabilization, pressure management, identification and mitigation of potential release pathways, and CO_2 utilization. This technology area is sub-divided into three research areas.

The Geologic Storage Technologies and Simulation and Risk Assessment area is developing technologies that can improve containment and injection operations, increase reservoir storage efficiency, assess risks, and mitigate potential release of CO_2 in all types of storage formations. Research conducted in the near- and long-term will augment existing technologies to demonstrate storage of CO_2. Advances in the scientific understanding of fluid flow, geomechanical, and geochemical processes rely upon computer simulators, in combination with laboratory measurement of modeling parameters and field validation. Simulation also plays a critical role in the design of injection strategies and monitoring programs for a storage project.

The Monitoring, Verification, Accounting (MVA), and Assessment area is designed to confirm permanent onshore and offshore CO_2 storage in geologic formations through monitoring capabilities that are reliable and cost effective. Monitoring is an important aspect of CO_2 injection, because it focuses on a number of permanence issues. Monitoring technologies are being developed for atmospheric, near-surface, and onshore and offshore subsurface applications to ensure that injection, abandoned, and monitoring wells are structurally sound and that CO_2 will remain within the storage complex.

The Carbon Use and Reuse area focuses on pathways and novel approaches for reducing CO_2 emissions by developing beneficial uses for CO_2, such as the conversion of CO_2 to useable products like polycarbonate plastics, mineralization and cement, or fuels and chemicals, with revenue offsetting a portion of the costs.

The **Storage Infrastructure** technology area focuses on conducting current and future research in the field, including carrying out regional characterization and field validation testing to demonstrate that different storage types in various depositional environments, distributed over different geographic regions, both onshore and offshore, have the capability to safely and permanently store CO_2. This research will provide a sound basis for commercial-scale CO_2 projects. The Storage Infrastructure technology area works to validate new technologies and benefits from specific solutions developed in the Core Storage R&D component. In turn, data gaps and lessons learned from small- and large-scale field projects are fed back to the Core Storage R&D component to guide future R&D.

Experience and knowledge gained through the Regional Carbon Sequestration Partnerships (RCSP) Initiative large-scale field projects is providing a firm foundation for future large-volume field projects, both onshore and offshore. The RCSP Initiative has been instrumental in developing processes and procedures for site characterization applicable for future commercial-scale projects. In addition to work conducted through the RCSPs, research within storage infrastructure is focused on offshore prospective storage resource assessment, and "fit-for-purpose" projects such as efforts to characterize and understand residual oil zones as a possibility for "net carbon negative oil."

Strategic Program Support activities contribute to an integrated domestic and international approach to ensure that CCS technologies are cost-effective and commercially available. The activities bring strategically focused expertise and resources to bear on issues that are key to commercial deployment of storage technologies. The Carbon Storage Program relies on International Collaborations to complement the program's approach to reducing CO_2 emissions. DOE is partnering with the IEA Greenhouse Gas R&D Program (IEAGHG) and the Carbon Sequestration Leadership Forum (CSLF), and is also engaged in a number of large-scale CCS demonstration projects around the world. Another example of the program's integrated approach is the DOE Subsurface Technology and Engineering Research Team (SubTER), which identifies and facilitates crosscutting subsurface R&D and policy priorities. This new initiative is focusing on subsurface research, such as discovering, characterizing, predicting, and monitoring the subsurface; accessing wells and their integrity; engineering and permeability control; and sustained production while sustaining the environment.

The Strategic Program Support technology area also supports the National Laboratory network and the National Risk Assessment Partnership. The National Laboratory network participates in collaborative research efforts. Research includes the evaluation of new technology concepts, products, and materials that are strategically targeted to address high priority research gaps. This strategic support activity also includes the development of the Energy Data eXchange™ (EDX), an online system providing access to information and data relevant to fossil and renewable energy systems. The National Risk Assessment Partnership (NRAP) is a DOE multi-national laboratory initiative that will continue to harness core capabilities developed across the national laboratories in order to carry out science-based prediction of the critical behavior of engineered-natural systems that can be applied to risk assessment for safe, long-term CO_2 storage.

1.2 The Carbon Storage Peer Review Projects

For this Carbon Storage Peer Review Meeting, 12 projects from the program were reviewed. These projects are listed on the following table. The Project Number, Performer, Project Objective and the technical area are also included.

	Project Number	Project Title	Performer	Objective	Technical Area
1	FE0012574	Greenhouse Gas Laser Imaging Tomography Experiment (Green Lite).	Exelis Inc.	This project will develop and test a greenhouse gas laser imaging tomography (Green LITE) system utilizing two scanning laser-based differential absorption sensors, combined with a series of retro-reflectors and intelligent algorithms, to measure CO_2 concentrations and generate 2-dimensional CO_2 flux maps over a geologic carbon storage site.	Monitoring tool development
2	FE0012173	Surface and Airborne Monitoring Technology for Detecting Geologic Leakage in a CO_2-Enhanced Oil Recovery Pilot, Anadarko Basin, Texas.	Oklahoma State University	The proposed research program is focused on the design and deployment of a grid of shallow subsurface and surface sensors in combination with low-altitude automated airborne (an unmanned aerial vehicle, or UAV) detection of CO_2 and CH_4.	Monitoring tool development
3	FE0012706	Real-Time In-Situ Carbon Dioxide Monitoring Network for Sensitive Subsurface Areas in Carbon Capture and Storage.	Intelligent Optical Systems Inc.	The focus of this project is to incorporate the fiber-optic CO_2 sensor previously developed by IOS with the pH and salinity fibers being developed by this research effort.	Monitoring tool development
4	FE0012266	Deep Controlled Source Electro-Magnetic Sensing: A Cost Effective, Long-Term Tool for Sequestration Monitoring.	Multi Phase Technologies LLC	The objective of the research is to develop and test a robust, cost-effective sensor array for long-term monitoring of CO_2 in deep geologic formations.	Monitoring tool development
5	FWP - ORD FY15 T4.1	Task 4.0 Monitoring Groundwater Impacts (Subtask 4.1) Develop and Demonstrate Monitoring Tools and Protocols for Groundwater Systems	NETL - Office of Research and Development	This study is focused on developing and demonstrating a suite of protocols and tools for new types of geochemically-based monitoring strategies for groundwater systems.	Field test for monitoring protocols
6	FWP - ORD FY15 T2.1	Task 2.0 Reservoir and Seal Performance (Subtask 2.1) Understanding Relative Permeability, Residual Saturation, and Porosity in Reservoirs to Reduce Uncertainty in Long-Term CO_2 Storage and Efficiency	NETL - Office of Research and Development	This study will focus on improving assessments of CO_2 storage for key reservoir classes by providing experimental measurements of critical properties at relevant subsurface conditions.	Experimental Lab measurements to simulate reservoir properties.

	Project Number	Project Title	Performer	Objective	Technical Area
7	FE0009301	Enhanced Analytical Simulation Tool for CO_2 Storage Capacity Estimation and Uncertainty Quantification	University of Texas at Austin	To develop an Enhanced Analytical Simulation Tool (EASiTool), which is intended for both technical and nontechnical users to achieve a fast, reliable, scientific estimate of CO_2 storage capacity for any potential geologic reservoir containing brine	Modeling
8	FWP - FEW0174	Enhanced porosity and permeability within carbonate CO_2 storage reservoirs: An experimental and modelling study	Lawrence Livermore National Laboratory (LLNL)	LLNL will conduct a high value follow-on experimental and modeling study to quantify the relationship between fluid flow, heterogeneity, and reaction rates specific to carbon storage in carbonate reservoirs by integrating characterization, solution chemistry, and simulated data.	Experimental & modeling study
9	FE0012665	Scalable Automated, Semi-Permanent Seismic Method for Detecting CO_2 Plume Extent During Geological CO_2 Injection	University of North Dakota	The goal of this project is to develop a proof-of-concept technology in which seismic surveying is used not to create a subsurface image, but rather to provide indications of physical changes occurring at monitored locations within the storage reservoir that signify the presence of CO_2.	Monitoring tool development
10	FE0009238	Optimal Model Complexity in Geological Carbon Sequestration: A Response Surface Uncertainty Analysis	University of Wyoming	The proposed study aims to investigate fundamental model complexity in representing coupled physical and chemical processes that accompany carbon storage operations in hierarchical subsurface geologic media.	Model development
11	FE0006821	Small-Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas.	University of Kansas Center for Research	This project aims to inject at least 40,000 metric tons of CO_2 under super-critical conditions into the Lower Arbuckle Group in Sumner County, Kansas. The project will use state-of-the-art monitoring techniques to track and visualize the location of stored CO_2 as well as estimate the amount of CO_2 in solution, as residual gas, and mineralized for both injection efforts.	Small-scale field project
12	FE0006827	Central Appalachian Basin Unconventional (Coal/Organic Shale) Reservoir Small Scale CO_2 Injection Test.,	Virginia Polytechnic Institute and State University	This project will design and implement characterization, injection, and monitoring activities to test unconventional formations (coal and organic shales) ability to store CO_2 economically and safely as well as track the migration of CO_2.	Small-scale field project

2 Overview of the Peer Review Process

2.1 Peer Review Panel Identification and Selection

The U.S. Department of Energy (DOE), the Office of Fossil Energy, and the National Energy Technology Laboratory (NETL) are fully committed to improving the quality and results of their research projects. To support this goal, in fiscal year (FY) 2015, IEAGHG was invited to provide an independent, unbiased, and timely peer review of selected projects within the DOE Office of Fossil Energy's Carbon Storage Program. The peer review of selected projects within the Carbon Storage Program was designed to comply with requirements from the Office of Management and Budget.

Between March 2nd and 6th IEAGHG convened a panel of five leading academic and industry experts to conduct a five-day peer review of 12 research projects from the NETL Carbon Storage Program. At the conclusion of each project review, these recognized technical experts provided recommendations on how to improve the management, performance, and overall results of each individual research project.

In consultation with NETL, who chose the 12 projects for review, IEAGHG selected an independent Peer Review Panel, facilitated the peer review meeting, and prepared this report to summarize the results. IEAGHG proposed the selected experts on the basis of their expertise in the development of monitoring technologies, Monitoring, Verification and Accounting (MVA), subsurface modeling and demonstration projects. IEAGHG also recommended a Review Panel Chair. The Chair has participated in similar peer reviews and, therefore, had an understanding of the peer review process and the role of the panel members.

IEAGHG performed this project review work as a subcontractor to the NETL contractor Leonardo Technologies, Inc.

2.2 Pre-Meeting Preparation

Several weeks before the peer review, each project team submitted a project technical summary and a draft final PowerPoint slide deck for presentation at the peer review meeting. Additionally, the appropriate federal project manager provided the project management plan and other relevant materials, including project fact sheets, quarterly and annual reports, and published journal articles that would help the peer review panel evaluate each project. The panel received all of these materials prior to the Peer Review Meeting via a peer review SharePoint site, which enabled the panel members to prepare for the meeting with the necessary project background information to thoroughly evaluate each project.

To increase the efficiency of the peer review meeting, a pre-meeting orientation WebEx was held with the review panel, the Technology Manager of the Carbon Storage Program and the IEAGHG team, about one month prior to the meeting, to review the peer review process and to provide an overview of the program goals and objectives.

2.3 Peer Review Meeting Proceedings

At the meeting, each research team made an uninterrupted 30 minute PowerPoint presentation. The final two experimental injection projects were allowed 45 minutes to present their results. In all cases the presentations were followed by a 30-minute question-and-answer session with the panel. The panel then held a 90-minute discussion and evaluation of each project. The time allotted for project presentations was dependent on the individual project's complexity, duration, and breadth of scope. To facilitate a full and open discourse of project-related material between the project team and the panel, all sessions were limited to the panel, IEAGHG and DOE-NETL personnel and LTI support staff. The closed sessions ensured open discussions between the principal investigators and the panel. Panel members were also instructed to hold the discussions that took place during the question-and-answer session as confidential.

The panel discussed each project to identify and come to a consensus on each project's strengths, project weaknesses, and recommendations for project improvement. The panel designated all strengths and weaknesses as "major" or "minor" and ranked recommendations in priority order. The consensus strengths and weaknesses served as the basis for determining the overall project score in accordance with the Rating Definitions and Scoring Plan of the Peer Review Evaluation Criteria.

To facilitate the evaluation process, Leonardo Technologies, Inc. provided the panel with laptop computers that were preloaded with Peer Review Evaluation Criteria Forms for each project, as well as the project materials that the panel members were able to access via SharePoint prior to the peer review meeting.

2.4 Peer Review Evaluation Criteria

At the end of the group discussion for each project, the panel came to a consensus on an overall project score. The panel scored each project according to the following predetermined categories:

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

The Rating Definitions that informed scoring decisions are included in Appendix B of this report. NETL completed a Technology Readiness Assessment of its key technologies in 2014. The technology readiness level (TRL) of projects assessed in 2014 was provided to the panel prior to the peer review meeting. These assessments enabled the panel to appropriately score the review criteria within the bounds of the established scope for each project. Appendix C describes the various levels of technology readiness for storage projects.

3 Summary of Key Findings

This section summarizes the overall key findings of the 12 projects evaluated at the FY2015 Carbon Storage Program Peer Review.

3.1 Overview of Project Evaluation Scores

The project evaluation scores are summarised in Figure 1. It should be stressed that it is not the intention to compare different projects, the purpose of the chart is merely to provide a summary of the project scores. The panel was given latitude to assign scores between the explicit score categories.

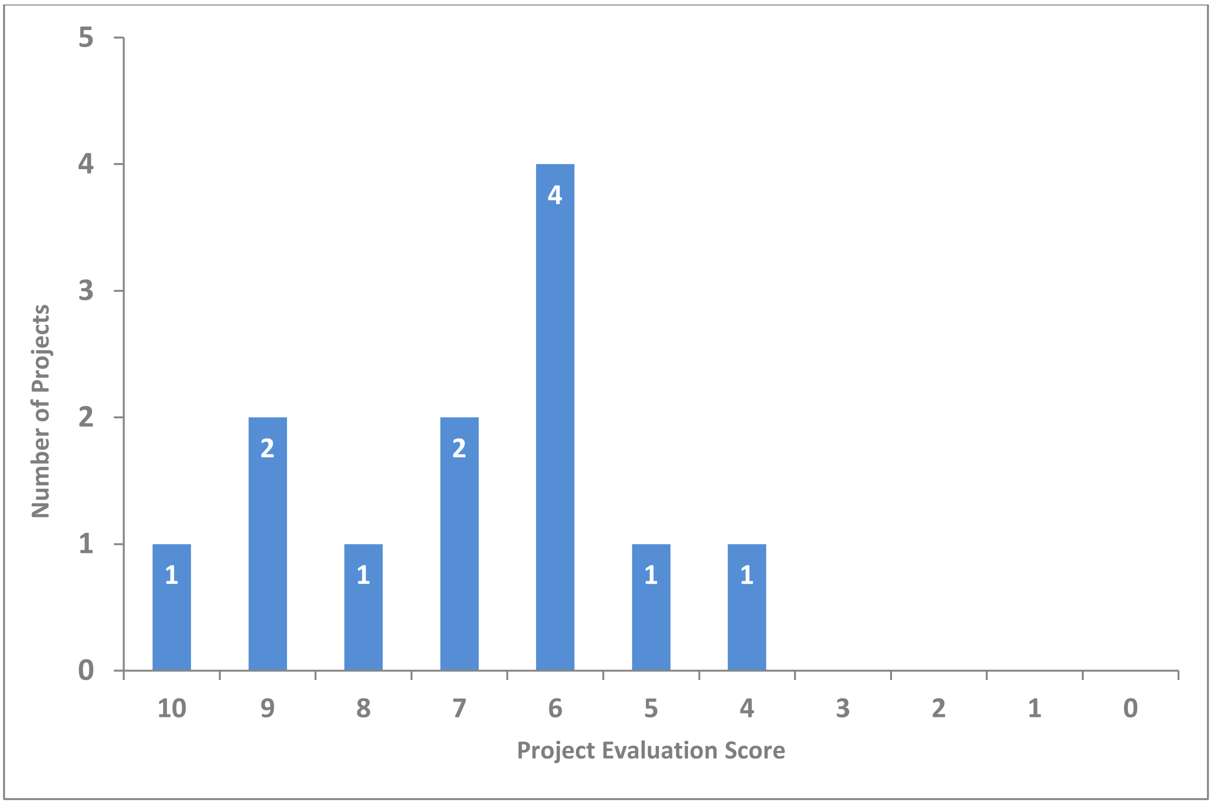


Figure 1 Carbon Storage Peer Review Project Evaluation Scores

The panel concluded that the review provided an excellent opportunity to comment on the relative strengths and weaknesses of each project. The presentations have provided additional clarity which has complemented the pre-meeting documentation. The review has also provided an insight into the range of technology development and the relative progress that has been made. The technical discussion has enabled the panel to contribute positively to each project's development by identifying core issues and by making constructive recommendations to improve project outcomes.

There was a consensus view that the quality achieved by some projects was impressive, although it was also recognised that some projects lacked focus on the DOE goals. It was noted that these projects have challenging objectives and in some cases not all the projects managed to meet their objectives. The panel discussions, particularly the recommendations, should help different project teams review key decisions or even modify their research.

It was recognised that the National Laboratory projects were of a different nature to those funded by Funding Opportunity Announcements and were consequently different to review.

As a general recommendation all projects should be encouraged to include a risk assessment and management activity so as to assist the achievement of their objectives.

The structure of the review and the variety of different projects, which included monitoring tool development, monitoring technique development, modeling and pilot scale injections, has stimulated interest and engagement that should also be useful for the DOE program especially the project managers.

4 Process Considerations for Future Peer Reviews

At the conclusion of this peer review meeting the panel and DOE-NETL management offered some positive feedback on the review process and provided constructive comments for enhancing future peer reviews.

The panel members thought that it would be helpful to have a single document that could provide all essential information on each project in a condensed format. Key elements should include: a project management plan; a risk management plan, a statement of the current status of the project including expenditure; and a Gantt chart showing a comparison of task progress against planned completion. There should be sufficient information in a condensed summary to form a view of each project's strengths and weaknesses. Guidance on the DOE-NETL perspective of each project in the context of the Carbon Storage Program would also be helpful.

Large projects could be allocated more time so that the PI can explain the complexity and detail of the project. It was suggested that the time allocation for the question and answer session should match the duration of the presentation. Linking individual panel member laptops electronically might offer an improved mechanism for producing written recommendations. The teleconferences in advance of panel review meetings proved to be helpful particularly for explaining the review criteria.

5 Review Project Summaries

5.1 Greenhouse Gas Laser Imaging Tomography Experiment (GreenLITE)

Jeremy Dobler, Exelis Inc.

Relevancy Statement

This project focuses on the development and testing of a novel system that is capable of detecting CO_2 leaks over large areas being considered for underground carbon storage, up to several square kilometers. Improved surface monitoring will quickly identify where remedial measures are needed to prevent CO_2 emissions to the atmosphere. Specifically, this project achieves its targets via remote active sensing technologies that quantitatively measure atmospheric CO_2 and that can generate two-dimensional (2-D) concentration and flux maps over the entire carbon storage field, which, in turn, will enable CO_2 leaks to be located, quantified and addressed based on real-time web interface.

Current Technology Readiness Level (TRL): 3
Planned end-of-project TRL: 6
DOE funding: $1,674,503
Cost share: DOE 80%; non-DOE 20%
Project start date: 10/1/2013
Project end date: 9/30/2015

5.2 Surface and Airborne Monitoring Technology for Detecting Geologic Leakage in a CO_2-Enhanced Oil Recovery Pilot, Anadarko Basin, Texas.

Jack Pashin and Peter Clark, Oklahoma State University

Relevancy Statement

This project focuses on developing surface and airborne technologies for detecting possible CO_2 leakage from storage sites. Better CO_2 near-surface monitoring methods allow project developers to more confidently and cost-effectively ensure that CO_2 is permanently stored and improved monitoring will contribute to better storage technology thus reducing CO_2 emissions to the atmosphere. Specifically, this project will develop new near surface and airborne monitoring technologies utilizing infrared gas analyzers, and integrate them with ground-based sampling in order to improve accuracy while minimizing the number of sensors, thereby reducing labor and maintenance costs.

Current Technology Readiness Level (TRL): 3
Planned end-of-project TRL: 6
DOE funding: $1,806,116
Cost share: DOE 80%; non-DOE 20%
Project start date: 10/1/2013
Project end date: 9/30/2016

5.3 Real-Time In-Situ Carbon Dioxide Monitoring Network for Sensitive Subsurface Areas in Carbon Capture and Storage

Jesus Delgado, Intelligent Optical Systems Inc.

Relevancy Statement

This project focuses on developing real-time near-surface monitoring capability for detecting possible CO_2 leakage in groundwater. Better CO_2 near-surface monitoring methods allow project developers to more confidently ensure that CO_2 is permanently stored, and understand impacts on groundwater, should a leak occur and this improved monitoring will contribute to better storage technology thus reducing CO_2 emissions to the atmosphere. Specifically, this project will develop a real-time fiber-optic system for the accurate detection of CO_2 and changes in pH, salinity and temperature in groundwater.

Current Technology Readiness Level (TRL): 2
Planned end-of-project TRL: 6
DOE funding: $1,199,523
Cost share: DOE 80%; Non-DOE 20%
Project start date: 10/1/2013
Project end date: 9/30/201

5.4 Deep-Controlled Source Electro-Magnetic Sensing: A Cost Effective, Long-Term Tool for Sequestration Monitoring.

Douglas LeBrecque, Multi-Phase Technologies LLC

Relevancy Statement

This project focuses on developing and demonstrating a permanent, autonomous, electrical geophysics monitoring system for tracking the CO_2 plume in the subsurface. A permanent, autonomous monitoring system will allow project developers to more confidently, and cost effectively, ensure that CO_2 is permanently stored. Improved monitoring will contribute to better storage technology; thus, reducing CO_2 emissions to the atmosphere. Specifically, this project will develop and field test controlled source electromagnetic methods with a borehole source to measure the electrical properties of CO_2 in the subsurface.

Current Technology Readiness Level (TRL): 3
Planned end-of-project TRL: 6
DOE funding: $466,469
Cost share: DOE 72%; Non-DOE 28%
Project start date: 10/1/2013
Project end date: 9/30/2016

5.5 Develop and Demonstrate Monitoring Tools and Protocols for Groundwater Systems

Dustin McIntyre, National Energy Technology Laboratory (NETL)

Relevancy Statement

This project focuses on developing methods to use natural geochemical signals for monitoring groundwater impacts associated with possible CO_2 release. Improved methods of groundwater monitoring will enable operators to more confidently ensure storage permanence, contributing to better storage technology and thus reducing CO_2 emissions to the atmosphere. Specifically, this project will carry out laboratory and field measurements to assess the application of the natural isotope tracers (Sr, Fe, Li, U), stable carbon isotopes, and organic compounds as natural geochemical tracers.

Current Technology Readiness Level (TRL): 3
Planned end-of-project TRL: 4
DOE funding: ~$750,000/year
Cost share: DOE 100% (FY16 through FY19 funding to be negotiated)
Project start date: 10/1/2013
Project end date: 9/30/2019

5.6 Understanding Relative Permeability, Residual Saturation, and Porosity in Reservoirs to Reduce Uncertainty in Long-Term CO_2 Storage and Efficiency

Dustin Crandall, National Energy Technology Laboratory (NETL)

Relevancy Statement

This subtask will aid in meeting the project objective of improving assessments of CO_2 storage for key reservoir classes by providing experimental measurements of critical properties at relevant subsurface conditions. This activity is focused on measuring relative permeability, porosity, and residual saturation at various conditions for samples from candidate storage sites and/or analogs, developing a database of relative permeability and residual saturation for key reservoir classes, and determining general trends and predictive relationships for relative permeability and residual saturation.

Current Technology Readiness Level (TRL): 2
Planned end-of-project TRL: 3
DOE funding: ~$950,000/year
Cost share: DOE 100%
Project start date: 10/1/2013
Project end date: 9/30/2019

5.7 Enhanced Analytical Simulation Tool (EASiTool) for CO_2 Storage Capacity Estimation and Uncertainty Quantification

Seyyed Hosseini, The University of Texas at Austin

Relevancy Statement

This project is focused on development of an analytical simulation tool EASiTool for CO_2 storage capacity estimation and uncertainty quantification. Development of improved reservoir modeling tools will enable project developers to more confidently predict storage capacity and ensure storage efficiency and permanence, contributing to better storage technology and thus reducing CO_2 emissions to the atmosphere. Specifically, this project will develop EASiTool, which includes a solution for pressure-build-up calculations, a simple geomechanical model coupled with a base model, and a net-present-value-based optimization algorithm that is a methodology for selecting the optimal number of required injection and extraction wells and new capacity and injectivity estimates under the brine-extraction process.

Current Technology Readiness Level (TRL): 3
Planned end-of-project TRL: 4
DOE funding: $795,896
Cost share: DOE 80%; non-DOE 20%
Project start date: 5/1/2013
Project end date: 4/30/2016

5.8 CO_2 Storage in Fractured Carbonate Reservoirs

Susan Carroll, Lawrence Livermore National Laboratory (LLNL)

Relevancy Statement

This project focuses on the calibration of key parameters in reactive transport models to be used to predict final storage of CO_2 in carbonate reservoirs and on calibrating NMR methods to estimate reservoir permeability from well logging tools. This project will advance science-based forecasting for the transition of CO_2-EOR operations to storage sites and for assessing impacts of pressure reservoir management through brine extraction for saline reservoir storage, thereby contributing to better storage technology for the reduction of CO_2 emissions to the atmosphere. Specifically, these efforts will improve current modeling methods via model calibration against experimental data on carbonate rocks from the Midale-Weyburn and Kansas Wellington storage projects.

Current Technology Readiness Level (TRL): 3
Planned end-of-project TRL: N/A
DOE funding: $1,810,000
Cost share: DOE 100%
Project start date: 10/1/2011
Project end date: 9/30/2015

5.9 Scalable Automated, Semi-Permanent Seismic Method for Detecting CO_2 Plume Extent During Geological CO_2 Injection

Charles Gorecki, University of North Dakota

Relevancy Statement

This project focuses on developing and demonstrating a scalable, automated, semipermanent seismic array (SASSA) method for tracking the CO_2 plume in the subsurface. Improved seismic methods will allow project developers to more confidently and cost-effectively ensure that the storage formation is being efficiently utilized and the CO_2 is permanently stored, and improved monitoring will contribute to better storage technology, thus reducing CO_2 emissions to the atmosphere. Specifically, this project will develop and demonstrate the use of an impulsive downhole source deployed semipermanently in combination with a sparse surface receiver array to track the CO_2 plume edge.

Current Technology Readiness Level (TRL): 3
Planned end-of-project TRL: 6
DOE funding: $2,400,000
Cost share: DOE 90%; non-DOE 20%
Project start date: 10/1/2013
Project end date: 3/31/2017

5.10 Optimal Model Complexity in Geological Carbon Sequestration: A Response Surface Uncertainty Analysis

Ye Zhang, University of Wyoming

Relevancy Statement

This project focuses on assessing how well upscaling and response surface methods represent coupled physical and chemical processes associated with CO_2 storage. Response surface methods and appropriate upscaling have the potential to enable project developers to more confidently predict storage capacity and ensure storage efficiency and permanence, contributing to better storage technology and thus reducing CO_2 emissions to the atmosphere. Specifically, this project will use a massively parallel, multicomponent-multiphase nonisothermal reactive flow and transport simulator to assess the efficacy of upscaled subsurface models and response surface methods applied to sedimentary environments.

Current Technology Readiness Level (TRL): 3
Planned end-of-project TRL: 4
DOE funding: $380,047
Cost share: DOE 80%; non-DOE 20%
Project start date: 10/1/2012
Project end date: 3/31/2016

5.11 Small-Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

Lynn Watney, University of Kansas Center for Research

Relevancy Statement

This project focuses on establishing the scientific basis to develop regional opportunities for storage in carbonate and clastic saline formations and depleted oil reservoirs in the Mid-Continent region. Field validation of characterization, modeling, monitoring, validation, accounting, and assessment and risk management technologies will demonstrate the ability to permanently and efficiently store CO_2 in these formations. Specifically, this project is conducting CO_2 injection for saline storage in the Arbuckle dolomite and basal sandstone and enhanced oil recovery (EOR) storage in the overlying Mississippian siliceous dolomite oil reservoir at Wellington field. Completion of the project will demonstrate safe and permanent storage of CO_2.

Current Technology Readiness Level (TRL): 5
Planned end-of-project TRL: 7
DOE funding: $11,484,494
Cost share: DOE 78%; non-DOE 22%
Project start date: 10/1/2011
Project end date: 9/30/2016

5.12 Central Appalachian Basin Unconventional (Coal/Organic Shale) Reservoir Small-Scale CO_2 injection Test

Nino Ripepi & Michael Karmis, Virginia Polytechnic Institute and State University

Relevancy Statement

This injection project focuses on better defining the regional opportunities for storage in coal and shale formations and provides the foundation for larger volume projects in the Appalachian region. Specifically, this project is performing an enhanced coalbed methane injection test where up to 20,000 metric tons of CO_2 will be injected into three legacy coalbed methane wells in Buchanan County, VA, and a huff-and-puff test in a Devonian Chattanooga shale gas well in Morgan County, TN. 463 metric tons of CO_2 were injected in a legacy horizontal gas well in March 2014. Completion of the project will demonstrate safe and permanent storage of CO_2.

Current Technology Readiness Level (TRL): 5
Planned end-of-project TRL: 7
DOE funding: $11,499,265
Cost share: DOE 80%; non-DOE 20%
Project start date: 10/1/2011
Project end date: 9/30/2016

6 Appendix A: Acronyms and Abbreviations

Acronym or Abbreviation	Definition
CCS	carbon capture and storage
CCUS	carbon capture, utilization, and storage
CO_2	carbon dioxide
DOE	U.S. Department of Energy
EOR	Enhanced Oil Recovery
Fe	Iron
FY	fiscal year
Li	Lithium
MVA	Monitoring, Verification, Accounting
NETL	National Energy Technology Laboratory
NMR	Nuclear Magnetic Resonance
OPPB	Office of Program Performance & Benefits
PISC	post-injection site care
PI	principal investigator
R&D	research and development
RD&D	research, development, and demonstration
scfm	standard cubic feet per minute
Sr	Strontium
TRL	Technology Readiness Level
U	Uranium
UAV	Unmanned Aerial Vehicle

7 Appendix B: Peer Review Evaluation Criteria

7.1 Evaluation Criteria.

EVALUATION CRITERIA	
1	**Degree to which the project, if successful, supports the program's near- and/or long-term goals** • Clear project performance and/or cost/economic* objectives are present, appropriate for the maturity of the technology, and support the program goals. • Technology is ultimately technically and/or economically viable for the intended application.
2	**Degree of project plan technical feasibility** • Technical gaps, barriers and risks to achieving the project performance and/or cost objectives* are clearly identified. • Scientific/engineering approaches have been designed to overcome the identified technical gaps, barriers and risks to achieve the project performance and/or cost/economic objectives*.
3	**Degree to which progress has been made towards the stated project performance and cost/economic* objectives** • Milestones and reports effectively enable progress to be tracked. • Reasonable progress has been made relative to the established project schedule and budget.
4	**Degree to which the project plan-to-complete assures success** • Remaining technical work planned is appropriate, in light of progress to date and remaining schedule and budget. • Appropriate risk mitigation plans exist, including Decision Points if appropriate.
5	**Degree to which there are sufficient resources to successfully complete the project** • There is adequate funding, facilities and equipment. • Project team includes personnel with needed technical and project management expertise. • The project team is engaged in effective teaming and collaborative efforts, as appropriate.

7.2 Rating Definitions

RATING DEFINITIONS	
10	**Excellent** – Several major strengths; no major weaknesses; few, if any, minor weaknesses. Strengths are apparent and documented.
8	**Highly Successful** – Some major strengths; few (if any) major weaknesses; few minor weaknesses. Strengths are apparent and documented, and outweigh identified weaknesses.
5	**Adequate** – Strengths and weaknesses are about equal in significance.
2	**Weak** – Some major weaknesses; many minor weaknesses; few (if any) major strengths; few minor strengths. Weaknesses are apparent and documented, and outweigh strengths identified.
0	**Unacceptable** – No major strengths; many major weaknesses. Significant weaknesses/deficiencies exist that are largely insurmountable.

8 Appendix C: Technology Readiness Level Descriptions

Carbon Storage Technology Readiness Levels

Research, Development, and Demonstration (RD&D) projects can be categorized based on the level of technology maturity. Listed below are nine (9) TRLs of RD&D projects managed by the NETL. These TRLs provide a basis for establishing a rational and structured approach to decision-making and identifying performance criteria that must be met before proceeding to the next level.

TRL 1 *- Basic principles observed and reported.* Lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples include paper studies of a technology's basic properties.

TRL 2 *- Technology concept and/or application formulated.* Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples include analytic and laboratory studies to confirm the potential practical application of basic processes and methods to geologic storage.

TRL 3 *- Analytical and experimental critical function and/or characteristic proof of concept.* Active R&D is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.

TRL 4 *- Component and/or system validation in a laboratory environment.* The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.

TRL 5 *- Laboratory-scale, similar-system validation in a relevant environment.* Laboratory validation of system/subsystem components. Laboratory validation testing of geologic storage processes, subsystems and/or subsystem components under conditions representative of in situ operation. Subsystem and/or component configuration is similar to (or matches) the final application in almost all respects. Validation testing involves measurements under in situ operating conditions to assess performance of the process, subsystem and/or component. Planning and design are undertaken for prototype system verification.

TRL 6 *- Engineering/pilot-scale prototypical system demonstrated in a relevant environment.* Laboratory validation of system/subsystem components. Laboratory validation testing of geologic storage processes, subsystems and/or subsystem components under conditions representative of in situ operation. Subsystem and/or component configuration is similar to (or matches) the final application in almost all respects. Validation testing involves measurements under in situ operating conditions to assess performance of the process, subsystem and/or component. Planning and design are undertaken for prototype system verification.

TRL 7 *- System prototype demonstrated in a plant environment.* Integrated pilot system demonstrated. Geologic storage system prototype tested at pilot scale for a type of depositional environment (e.g., saline fluvial deltaic) or storage type (e.g., EOR or enhanced coalbed methane [ECBM]). Pilot scale involves injection of a few hundred tonnes to several hundred thousand tonnes. System configured to enable pilot-scale testing, which involves measurements and operations specific to assessing performance of the system, subsystem, and subsystem components. Performance testing is relevant to each stage of the full lifecycle of a storage project, including site characterization, injection, and post-injection monitoring and closure. Planning and design are undertaken to test and demonstrate a full-scale system.

TRL 8* - *Actual system completed and qualified through test and demonstration in a plant environment.* System tested and demonstrated at final scale. This TRL represents the end of technology development for a geologic storage system for a type of depositional environment (e.g., saline fluvial deltaic) or storage type (e.g., EOR or ECBM). The complete geologic storage system is tested at final scale in a demonstration. Final scale involves injection of >1 million tonnes per year. System configured to enable final-scale testing, which involves measurements and operations specific to assessing performance of the system, subsystem, and subsystem components. Performance testing is relevant to each stage of the full lifecycle of a storage project, including site characterization, injection, and post-injection monitoring and closure.

TRL 9* - *Actual system operated over the full range of expected conditions.* System proven and ready for final-scale geologic storage. Geologic storage system is proven through successful operations at full scale for a type of depositional environment (e.g., saline fluvial deltaic) or storage type (e.g., EOR or ECBM). Full scale involves injection of >1 million tonnes per year. System configured for final-scale deployment, including considerations of cost. Operations include full lifecycle of the storage project, including site characterization, injection, and post-injection monitoring and closure.

* Not relevant to this Peer Review.

9 Appendix D: Meeting Agenda

AGENDA

FY15 Carbon Storage Peer Review

March 2 – 6, 2015

Sheraton Station Square

Pittsburgh, PA

Monday, March 02, 2015 – Ellwood Room

7:00 – 8:00 a.m.	Registration – 2nd Floor Foyer
8:00 – 8:45 a.m.	Peer Review Panel Kick-Off Meeting Open to Fossil Energy (FE), National Energy Technology Laboratory (NETL), and International Energy Agency Greenhouse Gas Research and Development (IEAGHG) staff only - NETL and IEAGHG Welcome - Role of Panel Chair - Peer Review Process Overview - Meeting Logistics
8:45 – 9:15 a.m.	Technology Manager/Office of Performance & Benefits (OPPB) and Panel Q&A Open to FE, NETL, and IEAGHG staff only - Carbon Storage Technology Manager – Traci Rodosta, NETL - OPPB – Dave Morgan, NETL
9:15 – 9:30 a.m.	BREAK
9:30 – 10:00 a.m.	01 – Project # FE0012574 - Greenhouse Gas Laser Imaging Tomography Experiment (Green Lite) *Jeremy Dobler* - Exelis Inc.

10:00 – 10:30 a.m.	Q&A
10:30 – 12:00 p.m.	Discussion
12:00 – 1:00 p.m.	Lunch (on your own)
1:00 – 1:30 p.m.	**02 – Project # FE0012173** - Surface and Airborne Monitoring Technology for Detecting Geologic Leakage in a CO_2-Enhanced Oil Recovery Pilot, Anadarko Basin, Texas *Peter Clark* - Oklahoma State University
1:30 – 2:00 p.m.	Q&A
2:00 – 3:30 p.m.	Discussion

Tuesday, March 3, 2015 – Ellwood Room

7:00 – 8:00 a.m.	Registration – 2nd Floor Foyer
8:00 – 8:30 a.m.	**03 – Project # FE0012706** - Real-Time In-Situ Carbon Dioxide Monitoring Network for Sensitive Subsurface Areas in Carbon Capture and Storage *Jesus Delgado* - Intelligent Optical Systems Inc.
8:30 – 9:00 a.m.	Q&A
9:00 – 10:30 a.m.	Discussion
10:30 – 10:45 a.m.	BREAK
10:45 – 11:15 a.m.	**04 – Project # FE0012266** - Deep Controlled Source Electro-Magnetic Sensing: A Cost Effective, Long-Term Tool for Sequestration Monitoring *Douglas LaBrecque* - Multi-Phase Technologies LLC
11:15 – 11:45 a.m.	Q&A
11:45 – 1:15 p.m.	Discussion

1:15 – 2:15 p.m.	Lunch (on your own)
2:15 – 2:45 p.m.	**05 – Project # FWP-ORD FY15 T4 Subtask 4.1** - Develop and Demonstrate Monitoring Tools and Protocols for Groundwater Systems
	Dustin McIntyre - National Energy Technology Laboratory (NETL)
2:45 – 3:15 p.m.	Q&A
3:15 – 4:45 p.m.	Discussion

Wednesday, March 4, 2015 – Ellwood Room

7:00 – 8:00 a.m.	Registration – 2nd Floor Foyer
8:00 – 8:30 a.m.	**06 – Project # FE00FWP-ORD-FY-15 T2 Subtask 2.1** - Understanding Relative
	Permeability, Residual Saturation, and Porosity in Reservoirs to Reduce Uncertainty in Long-Term CO_2 Storage and Efficiency
	Dustin Crandall - National Energy Technology Laboratory (NETL)
8:30 – 9:00 a.m.	Q&A
9:00 – 10:30 a.m.	Discussion
10:30 – 10:45 a.m.	BREAK
10:45 – 11:15 a.m.	**07 – Project # FE0009301** - Enhanced Analytical Simulation Tool for CO_2 Storage Capacity Estimation and Uncertainty Quantification
	Seyyed Hosseini - University of Texas at Austin
11:15 – 11:45 a.m.	Q&A
11:45 – 1:15 p.m.	Discussion
1:15 – 2:15 p.m.	Lunch (on your own)
2:15 – 2:45 p.m.	**08 – Project # FEW0174** - CO_2 Storage in Fractured Carbonate Reservoirs
	Susan Carroll- Lawrence Livermore National Laboratory (LLNL)

2:45 – 3:15 p.m. Q&A

3:15 – 4:45 p.m. Discussion

Thursday, March 5, 2015 – Ellwood Room

7:00 – 8:00 a.m. Registration – 2nd Floor Foyer

8:00 – 8:30 a.m. **09 – Project # FE0012665** – Scalable Automated, Semi-Permanent Seismic Method for Detecting CO_2 Plume Extent During Geological CO_2 Injection

Charles Gorecki - University of North Dakota

8:30 – 9:00 a.m. Q&A

9:00 – 10:30 a.m. Discussion

10:30 – 10:45 a.m. BREAK

10:45 – 11:15 a.m. **10 – Project # FE0009238** - Optimal Model Complexity in Geological Carbon Sequestration: A Response Surface Uncertainty Analysis

Ye Zhang - University of Wyoming

11:15 – 11:45 a.m. Q&A

11:45 – 1:15 p.m. Discussion

1:15 – 2:15 p.m. Lunch (on your own)

2:15 – 3:00 p.m. **11 – Project # FE0006821** – Small-Scale Field Test Demonstrating CO_2 Sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington Field, Sumner County, Kansas

Lynn Watney - University of Kansas Center for Research

3:00 – 3:30 p.m. Q&A

3:30 – 5:00 p.m. Discussion

Friday, March 6, 2015 – Ellwood Room

7:00 – 8:00 a.m.	Registration – 2nd Floor Foyer
8:00 – 8:45 a.m.	12 – Project # FE0006827 - Central Appalachian Basin Unconventional (Coal/Organic Shale) Reservoir Small Scale CO_2 Injection Test *Nino Ripepi and Michael Karmis*- Virginia Polytechnic Institute and State University
8:45 – 9:15 a.m.	Q&A
9:15 – 10:45 a.m.	Discussion
10:45 – 11:00 a.m.	BREAK
11:00 – 12:00 p.m.	Wrap-up Session