NATIONAL ENERGY TECHNOLOGY LABORATORY

FY18 OIL AND GAS PEER REVIEW OVERVIEW REPORT

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U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

DISCLAIMER

TABLE OF CONTENTS

Introduction and Background....1

Overview of the Peer Review Process....4

Summary of Key Findings....5

Project Synopses....6

Appendix A: Peer Review Evaluation Criteria Form....9

Appendix B: NETL Technology Readiness Levels....12

Appendix C: Meeting Agenda....17

Appendix D: Peer Review Panel Members....19

INTRODUCTION AND BACKGROUND

The National Energy Technology Laboratory's (NETL) overall research and development (R&D) effort focused on oil and natural gas incorporates four programs, each targeting specific R&D challenges:

- **Unconventional Oil and Natural Gas Resources**—Developing technologies to maximize resource recovery and reduce operational impacts from unconventional oil and gas development.
- **Offshore**—Minimizing the environmental impacts of deepwater and ultra-deepwater oil and natural gas production.
- **Methane Hydrates**—Improving the characterization of methane hydrates and developing ways to tap their massive energy potential.
- **Natural Gas Infrastructure**—Developing technologies and practices to assess and mitigate emissions from natural gas transmission, distribution, and storage facilities.

Several trends are currently converging, amplifying the need for continued research to ensure that the U.S. energy supply remains robust while keeping the environmental impact of developing that supply as low as possible.

- Energy demand continues to grow, and the need to limit energy imports for economic and energy security reasons remains strong.
- Natural gas remains an important element of any strategy to help the United States transition to a lower carbon energy footprint.
- Conventional domestic natural gas production is declining, and the primary alternative for replacing it (e.g., natural gas from hydraulically fractured shales) can lead to environmental impacts that must be avoided or reduced.
- Stakeholders are increasingly concerned about the environmental impacts of large-scale development of shale plays, and are interested in basing decisions on scientifically sound data that reflect the costs and benefits of energy development.
- The environmental benefits of using natural gas as a lower carbon energy source depend upon avoiding the emission of methane, a potent greenhouse gas, throughout the natural gas system.
- Methane hydrates, while not commercially competitive with other unconventional natural gas resources, are potentially a huge resource for the future and an important factor in understanding climate dynamics.

These issues have highlighted the need for good scientific data and more rapid technology development, both of which are objectives of the NETL research programs.

Currently, there are more than 80 active or recently completed extramural projects spread across the four oil and natural gas programs, valued at approximately $250 million (not including participant cost-share of at least 20 percent). The project leads and team members are balanced across producers, universities, state agencies, national laboratories, and technology providers. The distribution of projects within each program can be summarized as follows:

- **Unconventional Oil and Natural Gas Resources**—Over half of the projects are focused on enhanced recovery efficiency; about one fifth on reducing environmental impact; and the remaining projects are dedicated to advancing the basic understanding of unconventional oil and natural gas resources.
- **Offshore**—About one-half of the projects are focused on surface system safety and well stability, about one-third on subsea system reliability and automated safety features, and less than one-quarter on reducing well drilling and completion risks.
- **Methane Hydrates**—About one-fifth of the projects relate to exploration (geophysics); one-sixth on marine characterization; one-third on production technology; and the rest on the role of methane hydrates in the environment.
- **Natural Gas Infrastructure**—There are 12 projects in this program: seven projects are mitigation-focused research efforts that will work on developing a suite of natural gas leak reduction technologies and five projects advance methane emission quantification research to better measure and understand methane emissions derived from the natural gas supply chain.

Together, these four programs constitute a robust and balanced response to the challenges of ensuring a steady and environmentally sustainable supply of fossil fuels.

The three projects identified for evaluation during the Fiscal Year 2018 (FY18) Oil and Gas Peer Review fall within the Unconventional Oil and Natural Gas Resources project portfolio. The Unconventional Oil and Natural Gas Resources Program aims to find solutions to these environmental concerns by focusing on fundamental subsurface science; reservoir characterization; improved hydraulic fracturing; and reducing or mitigating impacts to air, water, or surface.

While many of the projects in the portfolio are set in the laboratory, a portion of the portfolio is specifically focused on research at “field laboratories.” These locations function as observatories where scientists can carry out data-gathering and test methods that can only be done on location with actual wells and facilities.

Office of Management and Budget Requirements

In compliance with requirements from the Office of Management and Budget, the U.S. Department of Energy (DOE) and NETL are fully committed to improving the quality of research projects in their programs. To aid this effort, DOE and NETL conducted an FY18 Oil and Gas Peer Review Meeting with independent technical experts to assess the projects’ technology readiness for work at the current Technology Readiness Level (TRL), the planned work to attain the next TRL, and offer recommendations. KeyLogic (NETL site-support contractor) convened a panel of leading academic and industry experts[i] on December 4-5, 2017, to conduct a two-day peer review of selected NETL-supported Oil and Gas Program research projects.

Overview of Office of Fossil Energy Oil and Gas Program Research Funding

The total funding of the three projects reviewed, over the duration of the projects, is $24,462,207. The funding and duration of the three projects that were the subject of this peer review are provided in Table 1.

TABLE 1. OIL AND GAS PEER REVIEW – PROJECTS REVIEWED

Project Number	Title	Lead Organization	Total Funding		Project Duration	
			DOE	Cost Share	From	To
FE0024314	Development And Field Testing Novel Natural Gas Surface Process Equipment For Replacement of Water as Primary Hydraulic Fracturing Fluid*	Southwest Research Institute (SwRI)	$1,312,000	$328,000	10/01/2014	03/31/2018
FE0024360	Injection and Tracking of Micro-seismic emitters to Optimize Unconventional Oil and Gas (UOG) Development*	Paulsson, Inc.	$4,378,000	$3,193,205	10/01/2014	09/30/2018
FE0024297	Marcellus Shale Energy and Environment Laboratory (MSEEL)**	West Virginia University	$10,454,942	$4,796,060	10/01/2014	03/31/2020
			$16,144,942	$8,317,265		
			$24,462,207			

* TRL-Based Evaluation: During TRL-based evaluations, the independent panel assesses the projects' technology readiness for work at the current TRL and the planned work to attain the next TRL.

** Recommendations-Based Evaluation: During recommendations-based evaluations, the independent panel provides recommendations to strengthen the performance of projects during the period of performance.

[i] Please see "Appendix D: Peer Review Panel Members" for detailed panel member biographies.

OVERVIEW OF THE PEER REVIEW PROCESS

DOE and NETL are fully committed to improving the quality and results of their research projects. Peer reviews are conducted to help ensure that the Office of Fossil Energy's (FE) research program, implemented by NETL, is compliant with the DOE Strategic Plan and DOE guidance. Peer reviews improve the overall quality of the technical aspects of R&D activities, as well as overall project-related activities, such as utilization of resources, project and financial management, and commercialization.

On December 4-5, 2017, KeyLogic (NETL site-support contractor) convened a panel of leading academic and industry experts (five experts on December 4; four experts on December 5) to conduct a two-day peer review of three research projects supported by the NETL Oil and Gas Program. Throughout the peer review meeting, these recognized technical experts offered recommendations and provided feedback on the projects' technology readiness for work at the current TRL and the planned work to attain the next TRL. In consultation with NETL representatives, who chose the projects for review, KeyLogic selected an independent peer review panel, facilitated the peer review meeting, and prepared this report to summarize the results.

Pre-Meeting Preparation

Before the peer review, each project team submitted a Project Technical Summary, Technology Maturation Plan (TMP) (if applicable), and the final presentation they would present at the peer review meeting. The appropriate Federal Project Manager (FPM) provided the project management plan and other relevant materials, including quarterly and annual reports (if applicable), and other technical papers or publications as additional resource materials for the panel. The panel received these materials prior to the peer review meeting, which enabled the panel members to fully prepare for the meeting with the necessary project background information to thoroughly evaluate the projects.

To increase the efficiency of the peer review meeting, pre-meeting orientation teleconference calls were held with the review panel and KeyLogic staff to review the peer review process and procedures, evaluation criteria, and project documentation, and allow for the Technology Manager to provide an overview of the program goals and objectives.

Peer Review Meeting Proceedings

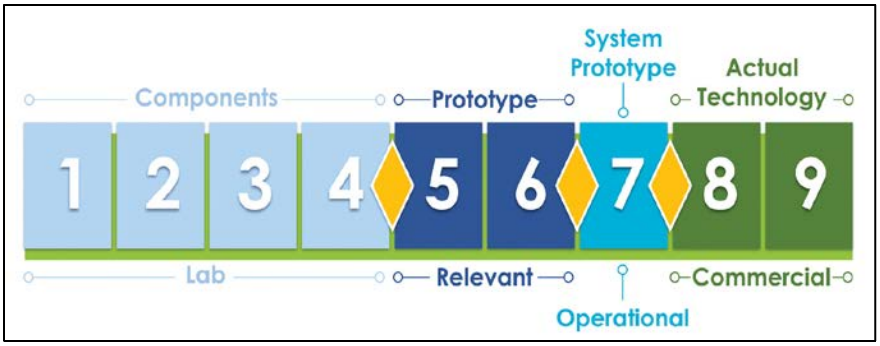
At the meeting, each project performer gave a presentation describing the project. The presentation was followed by a question-and-answer session with the panel and a closed panel discussion and evaluation. The time allotted for the presentation, the question-and-answer session, and the closed panel discussion was dependent on the project's complexity, duration, and breadth of scope. To facilitate a full and open discussion of project-related material between the project team and the panel, all sessions were limited to the panel, DOE/NETL personnel, and KeyLogic staff. The panel discussed each project to identify project strengths, project weaknesses, and recommendations in accordance with the Peer Review Evaluation Criteria. After the closed discussion on December 4, 2017, the panel offered prioritized recommendations and an evaluation of TRL gate transition readiness for each project. On December 5, 2017, the panel offered a series of prioritized recommendations to strengthen the project during the remaining period of performance.

SUMMARY OF KEY FINDINGS

This section summarizes the overall key findings of the projects evaluated at the FY18 Oil and Gas Peer Review Meeting.

Overview: Evaluation of TRL Gate Transition Readiness

NETL identifies key technology development gates as passing from (1) laboratory research to relevant environment research (TRL 4 to 5), (2) relevant environment research to operational system testing (TRL 6 to 7), and (3) operational system testing to successfully commissioned in an operating to commercial system (TRL 7 to 8).



Technology Readiness Levels and Decision Gates (in yellow)

At the meeting, the Peer Review Panel assessed each project's readiness to start work towards the next TRL based on a project's strengths, weaknesses, recommendations, issues, and concerns. For the various projects subject to review, the panel found that all were on track to attaining their respective planned end-of-project TRL based on achievement of the project goals as planned and addressing the Review Panel recommendations.

- Project #DE-FE0024314 has attained TRL 3. Upon achievement of their statement of work for Budget Period 3 and consideration of the panel's recommendations, Project #DE-FE0024314 will attain TRL 4.
- Project #DE-FE0024360 has attained TRL 3. Upon achievement of the Review Panel recommendations, Project #DE-FE0024360 will attain TRL 4. The Fiber Optic Seismic Vector Sensor (FOSVS) system is a TRL 6, moving to TRL 7 by the end of the project, while at present, the AMEs are a TRL 3, possibly attaining a TRL 4 if the recommendations are completed.

Project #DE-FE0024297 was subject to a recommendations-based evaluation. The Review Panel offered a series of prioritized recommendations to strengthen the project during the remaining period of performance. The prioritized recommendations were based on project strengths and weaknesses identified by the Review Panel.

PROJECT SYNOPSES

For more information on the Oil and Gas Program and project portfolio, please visit the NETL website: https://www.netl.doe.gov/research/oil-and-gas.

FE0024314

DEVELOPMENT AND FIELD TESTING NOVEL NATURAL GAS SURFACE PROCESS EQUIPMENT FOR REPLACEMENT OF WATER AS PRIMARY HYDRAULIC FRACTURING FLUID

Griffin Beck, Southwest Research Institute

Project Description: The goal of this project is to develop and field test the use of readily available natural gas collected at the wellhead as a primary fracturing fluid. An optimized, lightweight, and modular surface process involving natural gas liquefaction, compression, and injection will be developed and field tested to replace water as a cost-effective and environmentally-clean fracturing fluid. Using natural gas produced from the well for hydraulic fracture stimulation will result in a near-zero consumption of water. The gas, in a liquefied state, is injected as a fracturing fluid; it will mix with newly-released formation gas and both will be extracted to the surface. This eliminates the collection, waste, and treatment of large amounts of water, and reduces the environmental impact of transporting and storing the fracturing fluid.

Beginning TRL: 2

Current TRL: 4

Planned End-of-Project TRL: 4

DOE Funding: $1,312,000

Cost Share: $328,000

Duration: 10/01/2014 to 03/31/2018

FE0024360

INJECTION AND TRACKING OF MICRO-SEISMIC EMITTERS TO OPTIMIZE UNCONVENTIONAL OIL AND GAS (UOG) DEVELOPMENT

Bjorn Paulsson, Paulsson Inc.

Project Description: Paulsson will build a borehole seismic system that overcomes the short falls of the current borehole seismic acquisition and processing technologies. The new borehole seismic system will allow deployment in both vertical and horizontal wells, which is not possible with commercial systems today without using expensive and fragile well tractors for the deployment. The new borehole seismic system will have a bandwidth from ~0 Hz to 6,000 Hz, which is much broader than provided by any existing commercial system. The new system will be about 100 times more sensitive than geophone based systems. The new system will deploy sensors with an 80-dB rejection of out of plane seismic energy. The new system will allow for deployment in deeper wells, at higher pressures and temperatures than what is possible today. In combination, the new fiber optic-based seismic sensor will record far superior data, which will allow for the generation of superior images and superior detection and location of microseismic events.

Beginning TRL: 4

Current TRL: 6

Planned End-of-Project TRL: 7

DOE Funding: $4,378,000

Cost Share: $3,193,205

Duration: 10/01/2014 to 09/30/2018

FE0024297

MARCELLUS SHALE ENERGY AND ENVIRONMENT LABORATORY (MSEEL)

Tim Carr, West Virginia University

Project Description: West Virginia University and The Ohio State University have formed a consortium of university researchers to develop a research program focused on a dedicated field site and laboratory at the Northeast Natural Energy (NNE) production site in the center of the Marcellus Shale unconventional production region of north-central West Virginia. The MSEEL project will provide a long-term field site at NNE’s Morgantown Industrial Park (MIP) outside of Morgantown, West Virginia. The site provides a well-documented baseline of production and environmental characterization from two previous wells. A dedicated scientific observation well will be used to collect detailed subsurface data and to monitor and test technologies in additional production wells that may be drilled at the site. The MSEEL site is expected to undergo multiple drilling events (separated by periods sufficient to analyze data) over the course of the five-year project, providing the ideal testing conditions for researchers. MSEEL will use the latest information technology to enable a broad, integrated program of open, collaborative science and technology development and testing. The initial project plan provides for the collection of samples and data and/or the testing and demonstration of advanced technologies, but the phased approach is flexible enough to incorporate new technology and science.

DOE Funding: $9,301,899

Cost Share: $4,342,480

Duration: 10/01/2014 to 09/30/2019

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APPENDIX A: PEER REVIEW EVALUATION CRITERIA FORM

PEER REVIEW EVALUATION CRITERIA AND GUIDELINES

Peer reviews are conducted to ensure that the Office of Fossil Energy's (FE) research program, implemented by the National Energy Technology Laboratory (NETL), is compliant with the U.S. Department of Energy (DOE) Strategic Plan and DOE guidance. Peer reviews improve the overall quality of the technical aspects of research and development (R&D) activities, as well as overall project-related activities, such as utilization of resources, project and financial management, and commercialization.

In the upcoming NETL peer review, a significant amount of information about the projects within its portfolio will be covered in a short period. For that reason, NETL has established a set of rules for governing the meeting so that everyone has an equal chance to accurately present their project accomplishments, issues, recent progress, and expected results for the remainder of the performance period (if applicable).

The following pages contain the criteria used to evaluate each project. Each criterion is accompanied by multiple characteristics to further define the topic. Each reviewer is expected to independently assess all the provided material for each project prior to the meeting and engage in discussion to generate feedback for each project during the meeting.

Technology Readiness Level (TRL)-Based Evaluation

At the meeting, the Facilitator and/or Panel Chairperson will lead the Peer Review Panel in assessing a project's readiness to start work towards the next TRL based on a project's strengths[ii], weaknesses[iii], recommendations, issues, and concerns. NETL identifies key technology development gates as passing from (1) laboratory research to relevant environment research (Technology Readiness Level [TRL] 4 to 5), (2) relevant environment research to operational system testing (TRL 6 to 7), and (3) operational system testing to successfully commissioned in an operating to commercial system (TRL 7 to 8). NETL TRL definitions are included below.

[ii] A strength is an aspect of the project that, when compared to the evaluation criterion, reflects positively on the probability of successful accomplishment of the project's goal(s) and objectives.

[iii] A weakness is an aspect of the project that, when compared to the evaluation criterion, reflects negatively on the probability of successful accomplishment of the project's goal(s) and objectives.

Recommendations-Based Evaluation

At the meeting, the Facilitator and/or Panel Chairperson will lead the Peer Review Panel in identifying strengths, weaknesses, and prioritized recommendations for each project.

Under a recommendation-based evaluation, strengths and weaknesses shall be characterized as either "major" or "minor" during the Review Panel's discussion at the meeting. For example, a weakness that presents a significant threat to the likelihood of achieving the project's stated technical goal(s) and supporting objectives should be considered "major," whereas relatively less significant opportunities for improvement are considered "minor."

A **recommendation** shall emphasize an action that will be considered by the project team and/or the U.S. Department of Energy (DOE) to be included as a milestone for the project to correct or mitigate the impact of weaknesses, or expand upon a project's strengths. A recommendation should have as its basis one or more strengths or weaknesses. Recommendations shall be ranked from most important to least, based on the major/minor strengths/weaknesses.

NETL Peer Review Evaluation Criteria
1. Degree to which the project, if successful, supports the DOE Program's near- and/or long-term goals.
• Program goals are clearly and accurately stated. • Performance requirements[1] support the program goals. • The intended commercial application is clearly defined. • The technology is ultimately technically and economically viable for the intended commercial application.
2. Degree to which there are sufficient resources to successfully complete the project.
• There is adequate funding, facilities, and equipment. • Project team includes personnel with the needed technical and project management expertise. • The project team is engaged in effective teaming and collaborative efforts, as appropriate.
3. Degree of project plan technical feasibility.
• Technical gaps, barriers, and risks to achieving the performance requirements are clearly identified. • Scientific/engineering approaches have been designed to overcome the identified technical gaps, barriers, and risks to achieve the performance requirements. • Remaining technical work planned is appropriate considering progress to date and remaining schedule and budget. • Appropriate risk mitigation plans exist, including Decision Points when applicable.

4. Degree to which progress has been made towards achieving the stated performance requirements.
• The project has tested (or is testing) those attributes appropriate for the next TRL. The level of technology integration and nature of the test environment are consistent with the aforementioned TRL definition. • Project progress, with emphasis on experimental results, shows that the technology has, or is likely to, achieve the stated performance requirements for the next TRL (including those pertaining to capital cost, if applicable). • Milestones and reports effectively enable progress to be tracked. • Reasonable progress has been made relative to the established project schedule and budget.
5. Degree to which an appropriate basis exists for the technology's performance attributes and requirements.
• The Technology Readiness Level (TRL) to be achieved by the end of the project is clearly stated[2]. • Performance attributes for the technology are defined[2]. • Performance requirements for each performance attribute are, to the maximum extent practical, quantitative, clearly defined, and appropriate for and consistent with the DOE goals as well as technical and economic viability in the intended commercial application.
6. The project Technology Maturation Plan (TMP) represents a viable path for technology development beyond the end of the current project, with respect to scope, timeline, and cost.
[1] If it is appropriate for a project to not have cost/economic-related performance requirements, then the project will be evaluated on technical performance requirements only. [2] Supported by systems analyses appropriate to the targeted TRL. See Systems Analysis Best Practices.

APPENDIX B: NETL TECHNOLOGY READINESS LEVELS

NETL Technology Readiness Levels

The National Energy Technology Laboratory (NETL) supports a wide range of research, development, and demonstration (RD&D) projects, from small, short-duration materials development and property characterization projects up to large-scale power plant demonstrations. The nature and complexity of the technology under development will have implications for the application of the Technology Readiness concept, particularly with respect to supporting systems analysis requirements.

Accompanying the Technology Readiness Level (TRL) definitions and descriptions provided in the table below are Systems Analysis Best Practices. These Best Practices serve as a critical resource to guide the identification of performance attributes and to establish corresponding performance requirements for a given technology which are, in turn, tied to the intended commercial application and higher-level goals (e.g., program goals). A systems analysis is carried out to estimate the performance and cost of the technology based on the information (e.g., experimental data) that is expected to be available at a particular TRL. The results, when compared with conventional technology, are used to inform the next stage of development and provide specific experimental and analysis success criteria (the performance requirements). The performance requirements that may be appropriately tested at a particular TRL must be substantially met, thereby supporting the feasibility of commercial success/goal achievement, prior to proceeding to the subsequent TRL. Note that, as with the TRL descriptions, these Systems Analysis Best Practices are "gate-in"; that is, prerequisites to achieving the associated TRL.

The scope of the project must be taken into account when applying the Systems Analysis Best Practices – they may not be strictly applicable as written to each project. For example, it is an unreasonable expectation for a project developing a sensor, or fuel cell cathode, or thermal boundary coating for a turbine airfoil to perform a full-scale power plant simulation to determine the performance requirements of the specific technology in the course of pursuing TRL 4. However, the project must explicitly tie the quantitative goals/objectives for the technology to referenced system studies as well as relevant industry and/or market requirements in such a manner that their pedigree is readily traceable. Science and Technology (S&T)/Technology Development and Integration Center (TDIC) management must ensure that this occurs through language in the Funding Opportunity Announcement (FOA) topic (and in the subsequent project Statement of Project Objectives [SOPO]/Project Management Plan [PMP]/Technology Maturation Plan [TMP]).

TRL	Definition	Description	Systems Analysis Best Practices
1	**Basic principles observed and reported**	Core Technology Identified. Scientific research and/or principles exist and have been assessed. Translation into a new idea, concept, and/or application has begun.	Assessment: Perform an assessment of the core technology resulting in (qualitative) projected benefits of the technology, a summary of necessary R&D needed to develop it into the actual technology, and principles that support of the viability of the technology to achieve the projected benefits.
2	**Technology concept and/or application formulated**	Invention Initiated. Analysis has been conducted on the core technology for practical use. Detailed analysis to support the assumptions has been initiated. Initial performance attributes have been established.	White Paper: A white paper describing the intended commercial application, the anticipated environment the actual technology will operate in, and the results from the initiation of a detailed analysis (that will at least qualitatively justify expenditure of resources versus the expected benefits and identify initial performance attributes).
3	**Analytical and experimental critical function and/or characteristic proof-of-concept validated**	Proof-of-Concept Validated. Performance requirements that can be tested in the laboratory environment have been analytically and physically validated. The core technology should not fundamentally change beyond this point. Performance attributes have been updated and initial performance requirements have been established.	Performance Model and Initial Cost Assessment: This performance model is a basic model of the technology concept, incorporating relevant process boundary conditions, that provides insight into critical performance attributes and serves to establish initial performance requirements. These may be empirically- or theoretically-based models represented in Excel or other suitable platforms. In addition, an initial assessment and determination of performance requirements related to cost is completed.
4	**Basic technology components integrated and validated in a laboratory environment**	Technology Validated in a Laboratory Environment. The basic technology components have been integrated to the extent practical (a relatively low-fidelity integration) to establish that key pieces will work together, and validated in a laboratory environment. Performance attributes and requirements have been updated.	System Simulation and Economic Analysis: These models incorporate a performance model of the technology (may be a simple model as developed for TRL 3, or something more detailed – either should be validated against empirical data gathered in the laboratory) into a model of the intended commercial system (e.g., power plant). In addition, an economic analysis (e.g., cost-of-electricity) of the technology is performed, assessing the impact of capital costs, operating and maintenance costs, and life on the impact of the technology and its contributions to the viability of the overall system in a commercial environment. These analyses serve to assess the relative impact of known performance attributes (through sensitivity analyses) and refine performance requirements in the context of established higher-level technical and economic goals (e.g., programmatic or DOE R&D goals). These models are typically created in process simulation software (e.g., ASPEN Plus) or other suitable platforms. DOE maintains guidance on the execution of techno-economic analyses[1].

TRL	Definition	Description	Systems Analysis Best Practices
5	**Basic technology components integrated and validated in a relevant environment**	Technology Validated in a Relevant Environment. Basic technology component configurations have been validated in a relevant environment. Component integration is similar to the final application in many respects. Data sufficient to support planning and design of the next TRL test phase have been obtained. Performance attributes and requirements have been updated.	System Simulation and Economic Analysis Refinement: A more detailed process model for the technology, validated against empirical data gathered in the laboratory, will be developed and incorporated into system simulations. This provides greater fidelity in the performance and cost estimation for the technology, facilitating updates to performance attributes and requirements (including updates to the economic analysis). This also allows greater evaluation of other process synergy claims (e.g., state-of-the-art technology is improved by the use of the new technology). Cost estimation should be either vendor-based or bottom-up costing approaches for novel equipment.
6	**Prototype validated in a relevant environment**	Prototype Validated in Relevant Environment. A prototype has been validated in a relevant environment. Component integration is similar to the final application in most respects and input and output parameters resemble the target commercial application to the extent practical. Data sufficient to support planning and design of the next TRL test phase have been obtained. Performance attributes and requirements have been updated.	System Simulation and Economic Analysis Refinement: Performance and cost models are refined based upon relevant environment laboratory results, leading to updated performance attributes and requirements. Preliminary steady-state and dynamic (if appropriate for the technology) modeling of all critical process parameters (i.e., upper and lower operating limits) of the system prototype is completed. Cost estimation should be either vendor-based or bottom-up costing approaches for novel equipment. Key process equipment should be specified to the extent that allows for bottom-up estimating to support a feasibility study of the integrated system.
7	**System prototype validated in an operational system**	System Prototype Validated in Operational Environment. A high-fidelity prototype, which addresses all scaling issues practical at pre-demonstration scale, has been built and tested in an operational environment. All necessary development work has been completed to support Actual Technology testing. Performance attributes and requirements have been updated.	System Simulation and Economic Analysis Refinement: Performance and cost models are refined based upon relevant environment and system prototype R&D results. The refined process, system and cost models are used to project updated system performance and cost to determine if the technology has the potential to meet the project goals. Performance attributes and requirements are updated as necessary. Steady-state and dynamic modeling all critical process parameters of the system prototype covering the anticipated full operation envelope (i.e., upper and lower operating limits) is completed. Cost models should be based on vendor quotes and traditional equipment estimates should be minimal.

TRL	Definition	Description	Systems Analysis Best Practices
8	**Actual technology successfully commissioned in an operational system**	Actual Technology Commissioned. The actual technology has been successfully commissioned for its target commercial application, at full commercial scale. In almost all cases, this TRL represents the end of true system development.	System Simulation and Economic Analysis Validation: The technology/system process models are validated by operational data from the demonstration. Economic models are updated accordingly.
9	**Actual technology operated over the full range of expected operational conditions**	Commercially Operated. The actual technology has been successfully operated long-term and has been demonstrated in an operational system, including (as applicable) shutdowns, startups, system upsets, weather ranges, and turndown conditions. Technology risk has been reduced so that it is similar to the risk of a commercial technology if used in another identical plant.	Commercial Use: Models are used for commercial scaling parameters.

[1] *Performing a Techno-economic Analysis for Power Generation Plants, DOE/NETL-2015/1726, July 2015.*

Glossary of Terms

Actual Technology: The final product of technology development that is of sufficient size, performance, and reliability—ready for use at the target commercial application. The technology is at Technology Readiness Levels (TRLs) 8–9.

Basic Technological Components Integrated: A test apparatus that ranges from (1) the largest, most integrated and/or most realistic technology model that can reasonably be tested in a laboratory environment, to (2) the lowest-cost technology model that can be used to obtain useful data in a relevant environment.

Commissioning/Commission: The actual system has become operational at target commercial conditions and is ready for commercial operations.

Concept and/or Application: The initial idea for a new technology or a new application for an existing technology. The technology is at TRLs 1–3.

Core Technology: The idea, new concept, and/or new application that started the research and development (R&D) effort. Examples include: (1) a new membrane material, sorbent, or solvent; (2) new software code; (3) a new turbine component; (4) the use of a commercial sensor technology in more durable housing; or (5) the use of a commercial enhanced oil recovery technology to store CO_2. Typically this is a project's intellectual property.

Economic Analysis: The process of estimating and assigning costs to equipment, subsystems, and systems, corresponding to models of and specifications for the commercial embodiment of the technology. Such analyses include the estimation of capital costs, as well as operating and maintenance costs. Component service life and corresponding replacement costs are often a crucial aspect of these analyses. See *Performing a Techno-economic Analysis for Power Generation Plants, DOE/NETL-2015/1726, July 2015,* for further guidance.

Fidelity: The extent to which a technology and its operating environment/conditions resemble that of the target commercial application.

Integrated: The functional state of a system resulting from the process of bringing together one or more technologies or subsystems and ensuring that each function together as a system.

Laboratory Environment: An environment isolated from the commercial environment in which lower-cost testing is performed to obtain high-quality, fundamental data at earlier TRLs. For software development, this is a small-scale, simplified domain for a software mockup.

Operational System: The environment in which the technology will be tested as part of the target commercial application.

Performance Attributes: All aspects of the technology (e.g., flux, selectivity, life, durability, cost, etc.) that must be tested or otherwise evaluated to ensure that the technology will function in the target commercial application, including all needed support systems. Systems analysis may assist in the identification of relevant performance attributes. It is likely that the performance attributes list will increase as the technology matures. Performance attributes must be updated as new information is received and formally reviewed at each TRL transition.

Performance Requirements: Criteria that must be met for each performance attribute before the actual system can be used at its target commercial application. These will be determined – typically via systems analysis - in consideration of program goals, requirements for market competitiveness for the target commercial application, etc. Performance requirements may change over time, and it is unlikely that all of them will be known at a low TRL.

Program: The funding program. The program goals will be used to judge project value and, in concert with systems analysis, will support acceptable performance requirements for the project. The funding program will also determine whether the system will be tested under one or several sets of target commercial applications.

Project: The funding mechanism for technology development, which often spans only part of the technology development arc. Some projects may contain aspects that lack dependence; these may have different TRL scores, but this must be fully justified.

Proof-of-Concept: Reasonable conclusions drawn through the use of low-fidelity experimentation and analysis to validate that the new idea—and resulting new component and/or application—has the potential to lead to the creation of an actual system.

Prototype: A test apparatus necessary to thoroughly test the technology, integrated and realistic as much as practical, in the applicable TRL test environment.

Relevant Environment: More realistic than a laboratory environment, but less costly to create and maintain than an operational environment. This is a relatively flexible term that must be consistently defined by each program (e.g., in software development, this would be "beta testing").

Systems Analysis: The analytic process used to evaluate the behavior and performance of processes, equipment, subsystems, and systems. Such analyses serve to characterize the relationships between independent (e.g., design parameters and configurations, material properties, etc.) and dependent variables (e.g., thermodynamic state points, output, etc.) through the creation of models representative of the envisioned process, equipment, subsystem, or system. These analyses are used to determine the variables important to desired function in the target commercial application (i.e., performance attributes) and the associated targets that must be achieved through R&D and testing to realize program and/or commercial goals (i.e., performance requirements). Models and simulations may use a variety of tools, such as Excel, Aspen Plus, Aspen Plus Dynamics, etc., depending upon the scope of the development effort and the stage of development. See *Performing a Techno-economic Analysis for Power Generation Plants, DOE/NETL-2015/1726, July 2015,* for further guidance.

Systems Analysis Best Practices: These best practices serve as a guide for the level of systems and economic analysis rigor and level of effort appropriate for each TRL. The scope of the project – the subject and nature the technology under development - must be considered when applying these best practices. For example, the analytical effort associated with the development of a thermal barrier coating is quite different than that appropriate to the development of a post-combustion CO_2 capture system.

Target Commercial Application: This refers to one specific use for the actual system, at full commercial scale, which supports the goals of the funding program. A project may include more than one set of target commercial applications. Examples are:

1. Technologies that reduce the cost of gasification may be useful for both liquid fuels and power production.
2. Technologies that may be useful to monitor CO_2 storage in more than one type of storage site.

Technology: The idea, new concept, and/or new application that started the research and development (R&D) effort plus other R&D work that must be done for the project's core technology to translate into an actual system.

Technology Aspects: Different R&D efforts, both within and external to any given project. Examples include material development, process development, process simulation, contaminant removal/control, and thermal management.

Validated: The proving of all known performance requirements that can reasonably be tested using the test apparatus of the applicable TRL.

APPENDIX C: MEETING AGENDA

Oil and Gas Peer Review
December 4-5, 2017
NETL-Pittsburgh Building 922 Room 106A

Monday, December 4, 2017

8:00 a.m.	Arrive at the NETL-Pittsburgh Entrance Gate for Security Check
8:15 – 8:30 a.m.	Escort Visitors to NETL-Pittsburgh Building 922 Room 106A
8:30 – 9:00 a.m.	Peer Review Panel Kickoff Session - Welcome - Peer Review Process and Meeting Logistics
9:00 – 9:45 a.m.	Project # FE0024314 – Development And Field Testing Novel Natural Gas Surface Process Equipment For Replacement of Water as Primary Hydraulic Fracturing Fluid – Southwest Research Institute *Griffin Beck* – Southwest Research Institute *Sandeep Verma* – Schlumberger-Doll Research Center
9:45 – 10:30 a.m.	Question and Answer Session
10:30 – 10:45 a.m.	BREAK
10:45 – 12:00 p.m.	Closed Discussion (TRL-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic peer review support staff attend as observers.*
12:00 – 1:00 p.m.	Lunch (onsite cafeteria; cash only, orders will be placed during 10:30 a.m. BREAK)
1:00 – 1:45 p.m.	Project # FE0024360 – Injection and Tracking of Micro Seismic Emitters to Optimize Unconventional Oil and Gas (UOG) Development – Paulsson, Inc. *Björn Paulsson* – Paulsson, Inc.
1:45 – 2:30 p.m.	Question and Answer Session
2:30 – 2:45 p.m.	BREAK
2:45 – 4:00 p.m.	Closed Discussion (TRL-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic peer review support staff attend as observers.*
4:00 p.m.	Adjourn

Tuesday, December 5, 2017

8:00 a.m.	Arrive at the NETL-Pittsburgh Entrance Gate for Security Check
8:15 – 8:30 a.m.	Escort Visitors to NETL-Pittsburgh Building 922 Room 106A
8:30 – 10:00 a.m.	Project # FE0024297 – Marcellus Shale Energy and Environment Laboratory (MSEEL) – West Virginia University *Timothy Carr* – West Virginia University
10:00 – 10:15 a.m.	BREAK
10:15 – 12:15 p.m.	Question and Answer Session
12:15 – 1:15 p.m.	Lunch (onsite cafeteria; cash only, orders will be placed during 10:00 a.m. BREAK)
1:15 – 3:15 p.m.	Closed Discussion (Recommendations-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic peer review support staff attend as observers.*
3:15 – 4:00 p.m.	Wrap-Up Session
4:00 p.m.	Adjourn

Visiting NETL-Pittsburgh: https://www.netl.doe.gov/about/visiting-netl

Approximate GPS: 1501 Wallace Rd, South Park, PA 15129

Latitude: 40.300521 | Longitude: -79.977682

APPENDIX D: PEER REVIEW PANEL MEMBERS

Oil and Gas Peer Review
December 4-5, 2017
NETL-Pittsburgh Building 922 Room 106A

Andrew Bunger, Ph.D.

Andrew Bunger is an assistant professor at the University of Pittsburgh in the Department of Civil and Environmental Engineering and the Department of Chemical and Petroleum Engineering, where he teaches hydraulic fracturing mechanics and applications and principles on soil mechanics. Dr. Bunger has a Ph.D. in Geological Engineering from the University of Minnesota and was awarded the Professor of the Year (Pittsburgh Section) by the American Society of Civil Engineers in 2016. Prior to joining the faculty at the University of Pittsburgh, Dr. Bunger was a Research Scientist and Group and Project Leader at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Melbourne, Australia, where he researched geomechanics and hydraulic fracturing laboratory investigation and mechanics.

Dr. Bunger serves on the Editorial Board for the Geotechnical Testing Journal at ASTM International, and is a member of the Australian Geothermal Energy Group and the International Partnership for Geothermal Technology Simulation Working Group. To date, he has more than 45 journal articles, 8 book chapters, more than 60 conference papers, and 1 patent. His research interests include hydraulic fracturing, interaction between shale formations and drilling fluids, emplacement mechanics of magma intrusions, fracture mechanics, poroelasticity, and stress measurement. Dr. Bunger is a member of the following professional societies: Society of Petroleum Engineers, American Geophysical Union, American Rock Mechanics Association, and American Society of Civil Engineers. Dr. Bunger will be serving on the review panel on December 4, 2017.

Charles Gorecki

Charles Gorecki is the Director of Subsurface Research and Development at the Energy & Environmental Research Center (EERC), where he is responsible for developing and managing programs and projects focused on conventional, unconventional, and enhanced oil and gas production; geologic storage of carbon dioxide (CO_2); geothermal; and other energy and environmental research. He serves as the Program Manager for the Plains CO_2 Reduction (PCOR) Partnership, a partnership funded by the U.S. Department of Energy's (DOE) Regional Carbon Sequestration Partnership (RCSP) Program. The PCOR Partnership is focused on assessing the technical and economic feasibility of capturing and storing CO_2 emissions from stationary sources in the northern Great Plains and adjacent area. Mr. Gorecki leads a multidisciplinary team of researchers working on developing monitoring, verification, and accounting concepts and technologies for large-scale CO_2 storage in deep saline formations and oil fields and the characterization of the geologic formations. Mr. Gorecki also manages projects related to CO_2 storage capacity estimation; novel reservoir surveillance and CO_2 storage monitoring techniques; and unconventional oil and gas resource modeling, characterization, and testing.

Mr. Gorecki's principal areas of interest and expertise include enhanced oil recovery (EOR); unconventional oil and gas research; and geologic CO_2 storage, specifically in the areas of reservoir and simulation engineering. He has also led several other national and international projects associated with CO_2 storage, the nexus of water and carbon capture and storage (CCS), and CO_2-EOR. Mr. Gorecki has authored many papers and given presentations on a variety of topics associated with CO_2-EOR and CO_2 storage throughout the world. He holds a B.S. degree in Geological Engineering from the University of North Dakota.

John Jeffers

John Jeffers has an M.S. in Geology and Geophysics from Rice University and is the Director of Geosciences for SW Appalachia at Southwestern Energy. He previously held the Director of Geosciences position for Fayetteville Shale from 2009 through 2013 and for New Ventures from 2013 through 2016. Mr. Jeffers' professional experience also includes Schlumberger Oilfield Services (Worldwide Subsurface Development Manager; Subsurface Manager, IPM, North and South America; Business Development Manager and New Ventures Negotiator; and Geoscience Project Manager) and Mobil Oil Corporation (Exploration Team Leader, Cameroon; Senior Geologist, E&P New Ventures Asia-Pacific; Senior Geologist, Global Interpretation Support; Exploration Geologist, United States; and Production Geologist, U.S. Onshore). He has six publications and one patent to his name, and is a member of the American Association of Petroleum Geologists, the Society of Petroleum Engineers, the Houston Geological Society, the Society of Decision Professionals, and the Association of International Petroleum Negotiators.

James Sorensen

James Sorensen is a Principal Geologist at EERC, where he is a principal investigator and task manager for projects related to CO_2 storage in geologic media and the sustainable development of tight oil resources. Mr. Sorensen's primary areas of interest and expertise are CO_2 utilization and storage in geologic formations, tight oil resource assessment and development, and environmental issues associated with the oil and gas industry. Since 2003, he has focused on the value-added use of CO_2 for EOR. Since 2009, he has conducted a variety of research projects to develop an improved understanding of the Bakken Petroleum System, including efforts to examine the potential to use CO_2 for EOR in the Bakken.

In 2011, Mr. Sorensen conducted an assessment of North American tight oil resources that was included in the National Petroleum Council's report to the U.S. Secretary of Energy on the potential of North America's abundant natural gas and oil resources. Mr. Sorensen received his B.S. degree in Geology from the University of North Dakota. He is a member of the Society of Petroleum Engineers and is an author or coauthor of more than 30 published papers.

Robert Will, Ph.D.

Robert Will recently worked as a Geoscience and Reservoir Engineering Advisor at Schlumberger Carbon Services. His experience includes reservoir simulation, geologic modeling, microseismic monitoring, data analysis, and seismic support; reservoir engineering and geotechnical support for the first successful U.S. Environmental Protection Agency Class VI CO_2 injection permit; and rock physics-based, time-lapse seismic integration for reservoir simulator calibration. He holds a Ph.D. in Petroleum Engineering from Texas A&M University, is a registered Professional Geophysicist in California, and is a member of the Society of Exploration Geophysicists and the Society of Petroleum Engineers.

Dr. Will has experience working on several CCS projects, including as a principal geologic modeler on Petroleum Technology Research Center's Aquistore Project, as well as the Rocky Mountain CCS Project, and as a project reservoir engineer on the Illinois State Geological Survey's Illinois Basin – Decatur Project. In addition, Dr. Will served as a principal geologic modeler with the Big Sky Carbon Sequestration Partnership (BSCSP), and assisted project modelers from the Southwest Partnership on Carbon Sequestration (SWP). BSCSP and SWP are two partnerships funded by DOE's RCSP Program.