NATIONAL ENERGY TECHNOLOGY LABORATORY
OIL & GAS

DOE Award No.: DE-FE00-28966

Research Performance Progress Report

(Period Ending 12/31/2017)

Impact of clays on the compressibility and permeability of sands during methane extraction from gas hydrate

Project Period (10/1/2016 to 9/30/2019)

Submitted by:
Dr. Jongwon Jung

Signature

Louisiana State University, Dept. of Civil and Environmental Engineering
DUNS #075050765
3505C Patrick Taylor Hall
Baton Rouge, LA 70803
Email: jjung@lsu.edu
Phone number: (225) 578-9471

Prepared for:
United States Department of Energy
National Energy Technology Laboratory

Submission Date

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY
Office of Fossil Energy

DISCLAIMER

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Background: The quantity of methane potentially recoverable from gas hydrate is large enough to motivate federally-supported production tests in several countries, which in turn motivates studies of reservoir production efficiency. Evaluating long-term production well viability involves modeling permeability evolution in the reservoir sediments around the production well because processes reducing the flow of gas into the production well also reduce the long-term economic viability of the well. Fine particles, such as clays, exist nearly ubiquitously in the permafrost and marine settings that typically host gas hydrate, and fines reacting to fluid flow by migrating and clogging pore throats can reduce flow toward the production well. Many fines are sensitive to variations in pore-fluid chemistry, swelling in reaction to in situ pore brine being displaced by fresh water liberated from hydrates during dissociation. Additionally, fine particles tend to collect at gas/water interfaces created by the multiphase flow of gas and water. Thus, as methane and fresh water flow from the hydrate-dissociation front toward the production well, fine particles in the reservoir sands, interbedded fine-grained layers and seal layers can be swelled, migrated (or both), potentially clogging pathways and limiting flow to the production well.

Objective: This project seeks to provide a quantitative basis for reservoir models to account for the impact of clays and other fine-grained material ("fines") on reservoir compressibility and permeability, two key factors controlling the flow of gas and fluids toward a production well. This overall objective is addressed through a combination of site-specific and more generalized, fundamental science goals:

Site-specific measurement goals: quantify the change in compressibility and permeability due to the reaction of fines to pore-water freshening in sediment from the 2015 NGHP-02 gas hydrates research cruise offshore India.

Fundamental measurements on pure fines goal: distinguish between, and quantify, mechanisms for sediment compressibility and permeability change due to physical and chemical responses of fines to the flow of freshened pore water and gas:

- Chemical response: quantify and catalog the sensitivity of pure fines (fines with only a single component, or "endmember" fines) to pore-water chemistry.
- Physical response: quantify the link between fines migration and clogging during single and multiphase flow.

ACCOMPLISHMENTS

The overall project timeline is shown in Figure 1. This report details activities in the first quarter of Year 2. A full list of milestones and Success Criteria is provided in the Appendix.

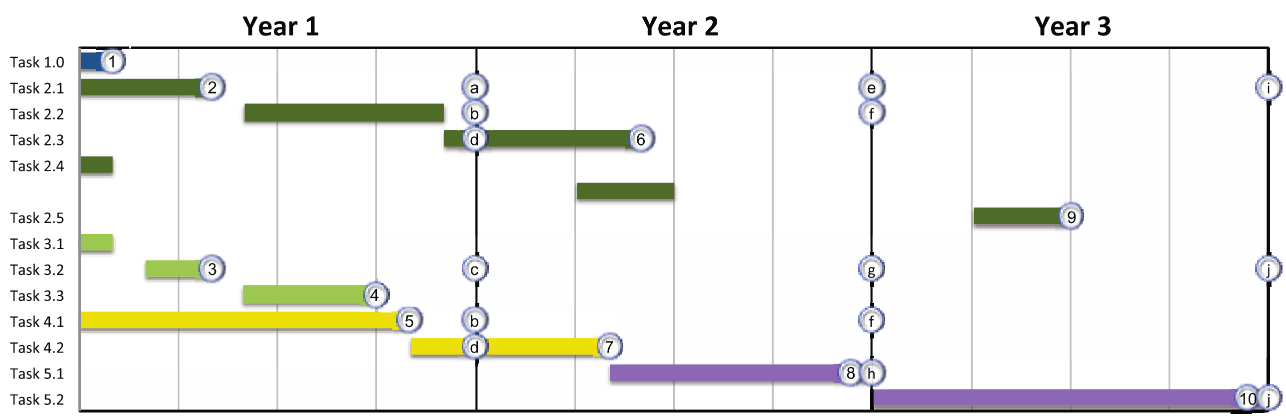

Figure 1: Project timeline, including times of activity (color bars), Milestones (numbered circles) and Success Criteria (lettered circles). A complete list of Milestones and Success Criteria are given in the Appendix.

Active Tasks this quarter included **2.3** (Microfluidic model visualization of NGHP-02 fines migration and clogging in a 2D pore network) and **4.2** (Dependence of fines migration and clogging on pore-fluid chemistry in porous media containing pure, endmember fines). A summary of accomplishments for each Task is provided below.

<u>Task 2.3: Microfluidic model visualization of NGHP-02 fines migration and clogging in a 2D pore network</u>

Natural sediments generally contain mixtures of the pure, endmember fines selected for this study. Mapping out the response of each endmember provides a guide for estimating the response of real sediment. Measurements on sediment from the 2015 NGHP-02 coring program offshore eastern India offer opportunities to examine how effectively the endmember results can be used to predict the response of natural material. In this quarter, micromodel tests on two high-value targets within the NGHP-02 program were completed. The primary interest of this study is in the migration of fines, so for most of the tests, specimens were sieved through a 75 μm mesh prior to injection into the micromodels. As a secondary check, a portion of an original, unsieved specimen was also tested. For comparison, the previous quarterly report showed how fine-grained silica silt in deionized water was found to clog 60 μm pore throats if the silica concentration by weight in the injection fluid was 0.5% or higher. For the NGHP-02 sediment, using only the fines sieved from the original specimen, clogging occurred in deionized water at concentrations of 0.2% or higher, even in 100 μm pore throats (Figure 2).

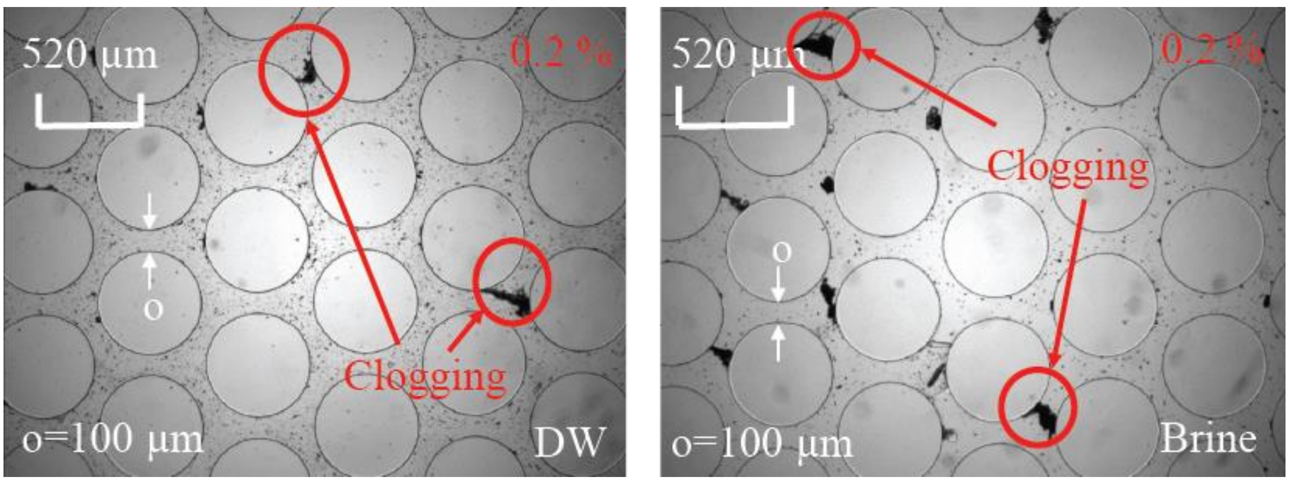

Figure 2: 2D micromodel images for NGHP-02 sediment. Pore throat width (distance between circular "particles") is 100μm, fines concentration is 0.2% by weight. (**left**) NGHP-02 particles suspended in deionized water (DW) are injected into the micromodel, saturating the micromodel and dispersing the sediment particles (black flecks in the pore space) relatively homogenously, though with enough clustering to form clogs. (**right**) NGHP-02 particles suspended in brine tend to cluster more readily than in deionized water (small dark regions adjacent to circular "particles"), and these clusters can cause pore-throat clogging (highlighted by red circles).

<u>Task 4.2: Dependence of fines migration and clogging on pore-fluid chemistry in porous media containing pure, endmember fines</u>

In addition to the mechanical drivers for pore-throat clogging by fines, there are chemical stimuli as well. Fine-grained particles are generally smaller than the pore throats they end up clogging, so the clogging behaviors studied in Task 4.1 are caused when clusters or clumps of fine-grained particles form, growing large enough to span the pore throats.

The tendency for fine-grain clusters to form depends strongly on interactions between the fines and the surrounding pore fluid. As shown in Figure 3, kaolinite demonstrates this capacity to cluster much more strongly when in the presence of a non-polar, low permittivity pore fluid (kerosene), than when in deionized water. As would be anticipated from the development of macroscopic clusters by kaolinite in kerosene, the concentration of kaolinite in kerosene required to clog even the large, 100 µm pore throats of the 2D micromodel is only 0.2%, a factor of 10 smaller than the concentration required in brine, and a factor of 25 smaller than the concentration required to form kaolinite clogs with deionized water.

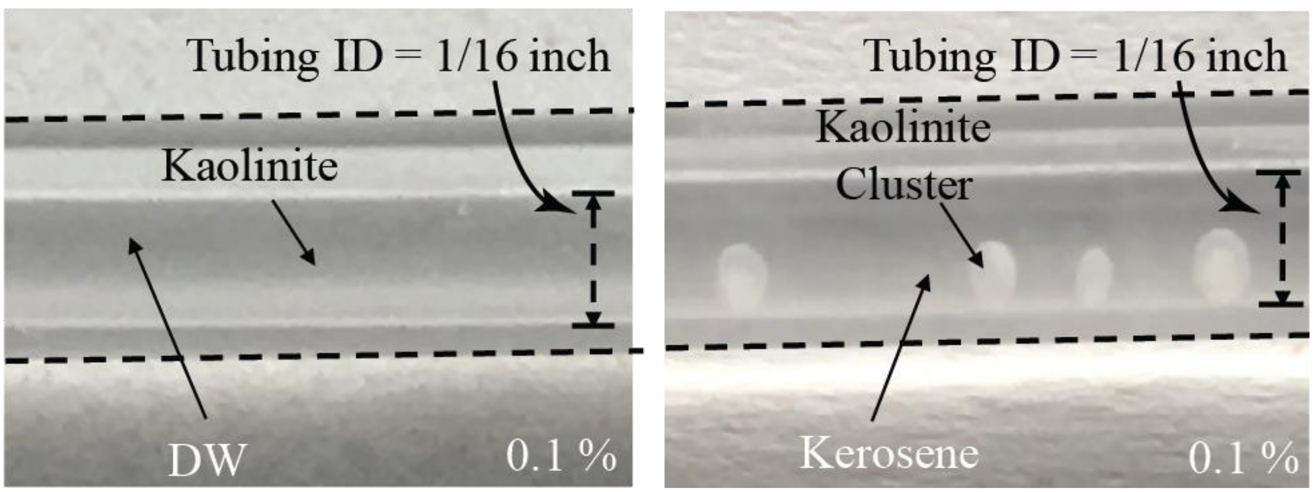

Figure 3: Kaolinite particles injected through a capillary tube at a concentration of 0.1% kaolinite by weight. (**left panel**) Kaolinite particles in deionized water are not attracted to each other strongly enough to form macroscopic clusters as the kaolinite and fluid flow through the capillary tube. (**right panel**) In the presence of a nonpolar, low permittivity fluid such as kerosene, kaolinite particles can rapidly form macroscopic clusters that hold together even while the kerosene and kaolinite are flowing through the tube. The speed at which particles can cluster, and the cohesiveness of those clusters, are important factors in determining the clogging potential of fines as a function of pore fluid type.

As noted in the previous quarterly report, the dependence of clustering on pore fluid chemistry depends on the nature of the fines involved. Fines whose behavior is governed by the overall surface charge (e.g. silica silt, bentonite) tend to form clusters more readily as the salinity increases.

Fines whose behavior is governed by the uneven distribution of electrical charge on the fine's surface (e.g. kaolinite and mica), tend to cluster and clog less readily with increasing pore water salinity. This quarter, working with the NGHP-02 specimens, it was found that clogs occurred more readily in brines than in deionized water (compare left and right panels of Figure 2). This has important implications for extracting methane from gas hydrates, because the extraction process causes gas hydrates to dissociate, freshening the water. It is anticipated that pore water freshening will help reduce clustering and clogging due to fines relative to the clustering and clogging that will occur in the system as water is being drawn into the production well prior to destabilizing the gas hydrate. A journal paper is in preparation, targeting the NGHP-02 special volume for the *Journal of Marine and Petroleum Geology* (initial submission deadline February 1,2018).

PRODUCTS

Cao, S.C., Jang, J., Waite, W.F., Jafari, M., Jung, J., A 2D micromodel study of fines migration and clogging behavior in porous media: Implications of fines on methane extraction from hydrate-bearing sediments [Abstract]. Talk presented at the 2017 Fall American Geophysical Union Conference, New Orleans, LA, December 11-15, 2017.

Jang, J., Waite, W.F., Jung, J., Pore-fluid sensitivity of clays and its impacts on gas production from hydrate-bearing sediments [Abstract]. Poster presented at the 9th International Conference on Gas Hydrates, June 25-30, 2017, Denver, Colorado.

Jang, J., Cao, S., Waite, W.F., Jung, J., Impact of pore-water freshening on clays and the compressibility of hydrate-bearing reservoirs during production. Conference paper accepted by the 9th International Conference on Gas Hydrates, June 25-30, 2017, Denver, Colorado.

APPENDIX: PROJECT TIMELINE & MILESTONE TRACKING

Figure A1 is the original complete Project timeline. Milestones and Success Criteria are listed thereafter, with updates given for elements in the current reporting period. Note that no milestones are associated with the current reporting period (Budget Period 1, First Quarter).

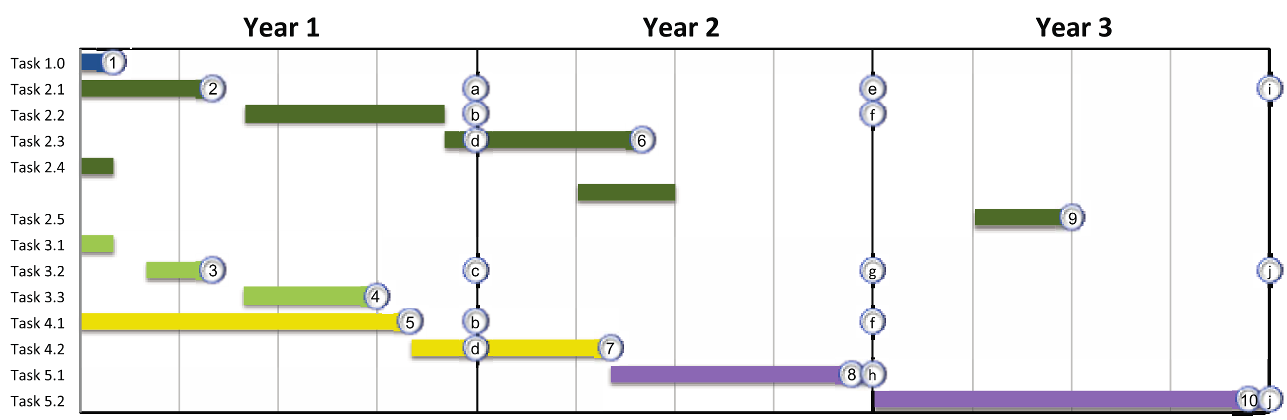

Figure A1: Original project timeline, including times of activity (color bars), Milestones (numbered circles) and Success Criteria (lettered circles). A complete list of Milestones and Success Criteria are given below.

<u>Milestones (listed according to the numbers given in Figure A1)</u>

Budget Period 1

1. Task 1, Project Management (LSU/USGS). This task will be completed October 31, 2016 and verified through DOE acceptance of the project SOPO, annual budget forecasts and Project Management Plan.

   <u>Status</u>: Completed. SOPO and PMP accepted by DOE. Kickoff meeting presentation complete.

2. Task 2, Site-specific pore fluid sensitivity study (USGS). This data acquisition component of Task 2 will be completed January 31, 2017 and verified through comparison of NGHP-02 data obtained with available shipboard data from the NGHP-02 cruise offshore India.

   <u>Status</u>: Initial phase of milestone completed. NGHP data has been collected on shipboard depressurized core material, but project will take the opportunity to collect additional data as pressure core material becomes available. Data will be integrated into a set of NGHP-02 special science volume papers currently with a February 2018 submission deadline.

3. Task 3, Endmember fines – electrical sensitivity index (USGS). This data acquisition component of Task 3 will be completed January 31, 2017. Results will be verified through duplicate measurements of targeted specimens using LSU equipment, literature comparison where available.

    Status: Completed. Data from this milestone have been incorporated into a conference paper and poster presented at the Ninth International Conference on Gas Hydrates (June 25- 30, 2017 in Denver, CO).

4. Task 3, Endmember fines – dependence of compressibility and permeability on pore fluid chemistry (LSU). This data acquisition component of Task 3 will be completed June 30, 2017. Results will be verified through duplicate measurements of targeted specimens using USGS equipment.

    Status: Completed. Data from this task is partly included in the conference paper and poster presented at the Ninth International Conference on Gas Hydrates (June 25-30, 2017 in Denver, CO). Remaining data are being incorporated into a manuscript for peer-reviewed journal publication.

5. Task 4, 2D micromodel studies – mechanical contribution of endmember fines to clogging (LSU). This data acquisition component of Task 4 will be completed July 31, 2017. Results will be verified through duplicate measurements of targeted specimens using USGS equipment.

    Status: LSU contribution completed. Data from this task is partly included in the conference abstract submitted to the Fall American Geophysical Union Conference (December 11-15, 2017 in New Orleans, LA). Remaining data are being incorporated into a manuscript for peer-reviewed journal publication. Micromodels to be used at the USGS will be constructed at LSU in the first quarter of BP 2 and shipped to the USGS.

Budget Period 2

6. Task 2, 2D micromodel studies – mechanical contribution of NGHP-02 fines to clogging (USGS). This data acquisition component of Task 2 will be completed March 1, 2018. Results will be verified through linkages between imaged clogs and measured evolution of pressure and flow parameters.
7. Task 4, 2D micromodel studies – clogging dependence of endmember fines on pore fluid chemistry (LSU). This data acquisition component of Task 4 will be completed January 31, 2018. Results will be verified through duplicate measurements of targeted specimens using USGS equipment.
8. Task 5, 3D visualization of clogging and clog fracturing – dependence on endmember fines (LSU). This task has been removed from the project, which will now end upon completion of BP2.

Budget Period 3

9. Task 2, Site-specific dependence of compressibility and permeability on pore fluid chemistry (USGS). This data acquisition component of Task 2 will be completed March 31, 2019. Results will be verified for brines and freshened pore water by comparisons with pressure core data obtained elsewhere in the NGHP-02 project. This task will be shifted into BP2 and incorporated into an NGHP-02 special science volume paper with a February 2018 submission deadline.

10. Task 5, 3D visualization of clogging and clog fracturing – dependence on pore water chemistry (LSU). This task has been removed from the project, which will now end upon completion of BP2.

Success Criteria (listed according to the letters given in Figure A1)

End of Budget Period 1

a. Subtasks 2.1, 2.4: NGHP-02 fines properties (Offshore India). Index property measurements and liquid limit tests should have begun on NGHP-02 conventional core sediment. Additional index property and liquid limit tests can be run on NGHP-02 material as the material becomes available from pressure cores that were previously dedicated for USGS study during NGHP-02.

   Status: Initial phase of criteria completed. NGHP data has been collected on shipboard depressurized core material, but project will take the opportunity to collect additional data as pressure core material becomes available. Data will be integrated into a set of NGHP-02 special science volume papers currently with a February 2018 submission deadline.

b. Subtasks 2.2 and 4.1 (linked): 2D microfluid models – clogging via physical processes. Measurements of clogging by endmember fines should have been run separately by both participants. Results should be quantified in terms of clogging potential due to mechanical activity (fines migration) and geometry (pore throat size relative to grain size of the fines). Results should demonstrate similar behavior within the subset of LSU and USGS tests that are paired for interlaboratory verification purposes.

   Status: LSU contribution completed. Data from this task is partly included in the conference abstract submitted to the Fall American Geophysical Union Conference (December 11-15, 2017 in New Orleans, LA). Remaining data are being incorporated into a manuscript for the NGHP-02 special science volume, with a February 2018 submission deadline. Micromodels to be used at the USGS will be constructed at LSU in the first quarter of BP 2 and shipped to the USGS.

c. Task 3: Endmember fines assessment of pore fluid chemistry impact on compressibility and permeability. All data for a manuscript detailing the implications of the electrical sensitivity (pore fluid sensitivity) of fines on compressibility and permeability should be in hand, and a conference abstract prepared.

__Status:__ Criteria complete. Conference paper and poster have been presented on this material at the Ninth International Conference on Gas Hydrates (June 25-June 30, 2017 in Denver, CO).

d. Subtasks 2.3 and 4.2 (linked): 2D microfluid models – clogging dependence on pore fluid chemistry. 2D micromodel experiments should have been started by both participants to assess the dependence of clogging by fines in relation to fluid chemistry. Initial comparisons between participants should guide subsequent efforts and dictate any additional tests that may need to be run.

__Status:__ LSU contribution completed. Data from this task is partly included in the conference abstract submitted to the Fall American Geophysical Union Conference (December 11-15, 2017 in New Orleans, LA). Remaining data are being incorporated into a manuscript for the NGHP-02 special science volume, with a February 2018 submission deadline. Micromodels to be used at the USGS will be constructed at LSU in the first quarter of BP 2 and shipped to the USGS.

End of Budget Period 2

e. Subtasks 2.1, 2.4: NGHP-02 fines properties (Offshore India). Index property measurements and liquid limit tests should continue on NGHP-02 pressure core sediment as the material becomes available from pressure cores that were previously dedicated for USGS study during NGHP-02. The publication moratorium should have expired in time to allow a conference abstract submission covering the NGHP-02 fines study to date.
f. Subtasks 2.2, 2.3 and Task 4: 2D Micromodel studies of clogging by endmember fines. All data for a manuscript detailing the implications of mechanical and chemical controls on clogging by endmember fines should be in hand. A joint manuscript should be submitted for peer reviewed journal publication, though the review process will likely be ongoing at the end of Budget Period 2.
g. Task 3: Endmember fines assessment of pore fluid chemistry impact on compressibility and permeability. Based on feedback from presenting this material at a conference, a peer-reviewed journal manuscript should have been written and submitted during this budget period, though the review process will likely be ongoing at the end of Budget Period 2.
h. Subtask 5.1: 3D micromodel imagery of the role of endmember fines in clogging, clog fracturing, and relative permeability. This Subtask is a 3D extension of the Subtasks 2.2 and 4.1 2D micromodel tests. By the end of Budget Period 2, comparisons between 2D and 3D observations of fines clogging based on mechanical and geometric factors should be providing insight into how the 2D micromodel results scale up to 3D, and these insights should be captured in a submitted conference abstract.

End of Budget Period 3

i. Subtasks 2.1, 2.4: NGHP-02 fines properties (Offshore India). Index property measurements and liquid limit tests should be complete on NGHP-02 pressure core sediment as the material. Based on feedback from presenting this material at a conference, a peer-reviewed journal manuscript should have been written and submitted during this budget period, though the review process for an NGHP-02 special volume may be ongoing even by the end of Budget Period 3.
j. Tasks 3 and 5: Interaction of fines with pore water – effect of pore water chemistry on index properties and flow behavior of endmember fines. Tying the macroscopic property insights from Task 3 with the 3D pore-scale behaviors observed in Task 5 provides the scientific content for the capstone publication in this project. Based on reviewer feedback from Task 3 and conference feedback from Subtask 5.1, a manuscript covering the interaction between fines and pore water and the subsequent impact on index and flow properties will be submitted.

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

13131 Dairy Ashford Road, Suite 225
Sugar Land, TX 77478

1450 Queen Avenue SW
Albany, OR 97321-2198

Arctic Energy Office
420 L Street, Suite 305
Anchorage, AK 99501

Visit the NETL website at:
www.netl.doe.gov

Customer Service Line:
1-800-553-7681

NATIONAL ENERGY TECHNOLOGY LABORATORY

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