Marcellus Shale Energy and Environment Lab (MSEEL)

Project Number (DOE Award No.: DE-FE0024297)

Timothy R Carr

West Virginia University

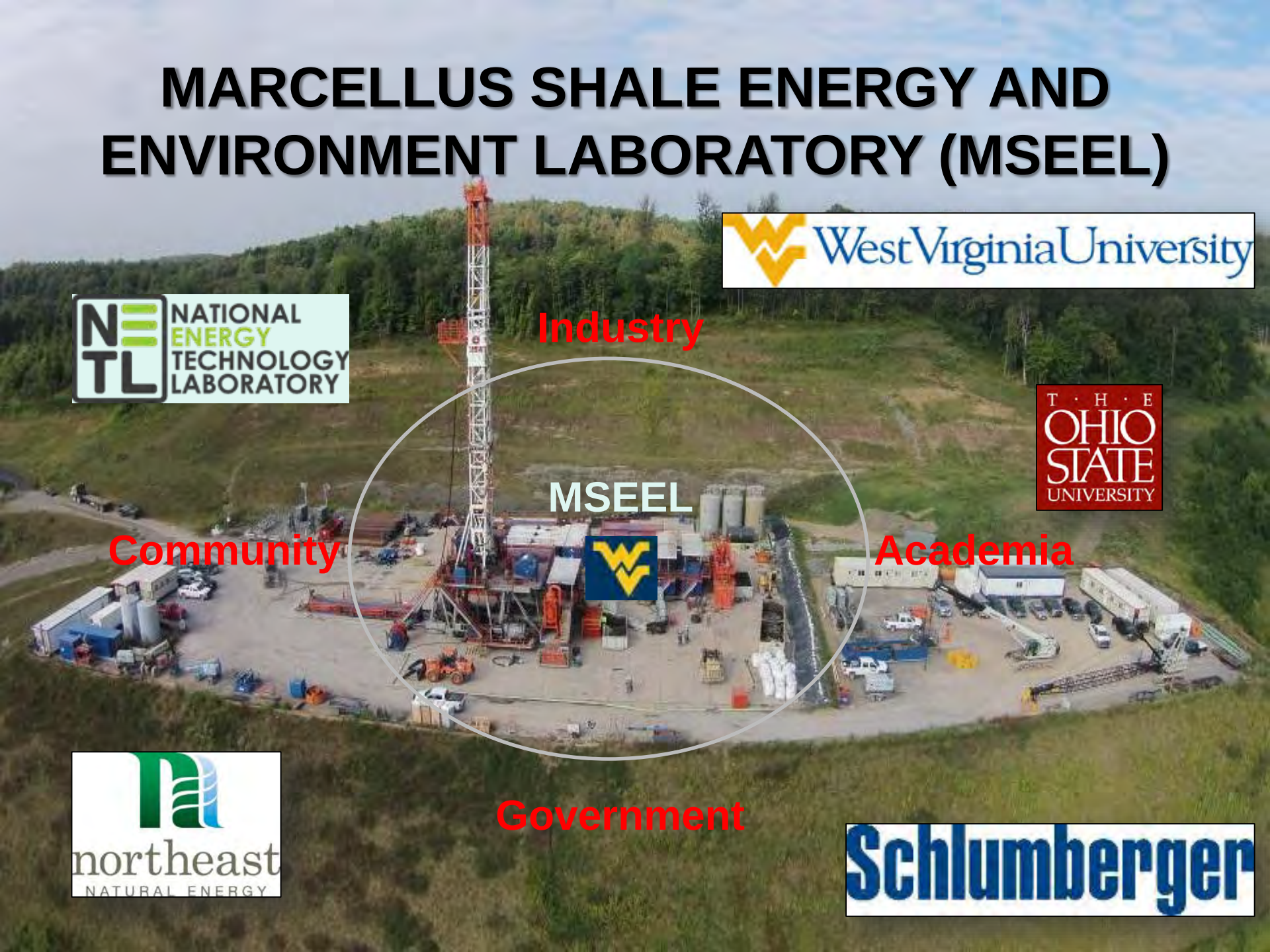
U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

MARCELLUS SHALE ENERGY AND ENVIRONMENT LABORATORY (MSEEL)



Presentation Outline

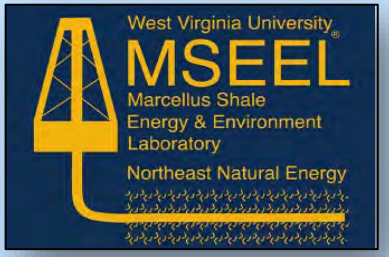
- Overview
  - Project Objectives
  - Marcellus shale and the MSEEL Project
- Progress to Date & Remaining Technical Issues (Task Level)
  - Data Dissemination and Technology Transfer (Maneesh Sharma)
  - Water and Solid Waste Monitoring (Paul Ziemkiewicz)
  - Engine Performance/emissions (Derek Johnson)
  - Bio/Geochemistry (Shikha Sharma)
  - Reservoir Characterization (Tim Carr)
- Project Accomplishments & Remaining Technical Issues
- Proposed Activities

Benefit to the Program

- Complete Documentation of a Shale Gas Well
  - Transparent Well
- Advances in Understanding of Technical Aspects
  - Deep Subsurface Geochemistry
    - Microbial and Biogeochemistry
  - Unconventional Fracture Models
  - Big Data Processing
  - Methods to Improve Stimulation Efficiency
  - Increased Production

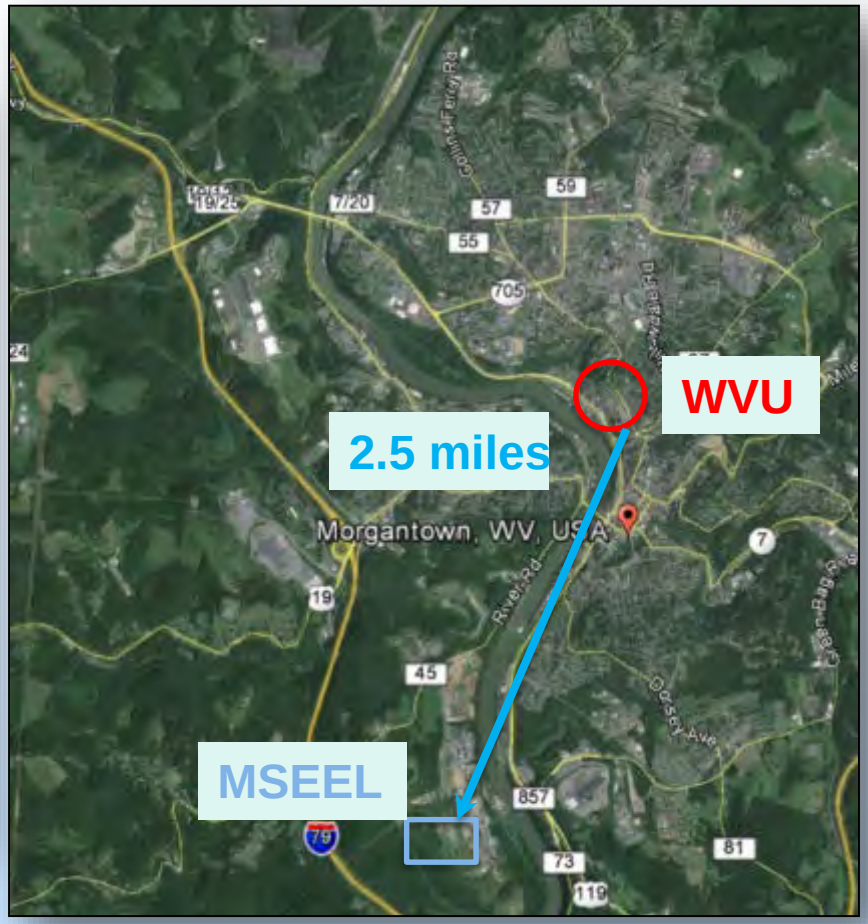
Project Overview:
Goals and Objectives

The goal and objective of the Marcellus Shale Energy and Environment Laboratory (MSEEL) is to provide a long-term collaborative field site to develop and validate new knowledge and technology to improve recovery efficiency and minimize environmental implications of unconventional resource development



MSEEL Site


MIP-5H
MIP-3H
MIP-SW
MIP-6H
MIP-4H
0.5 km


WVU
2.5 miles
Morgantown, WV, USA
MSEEL

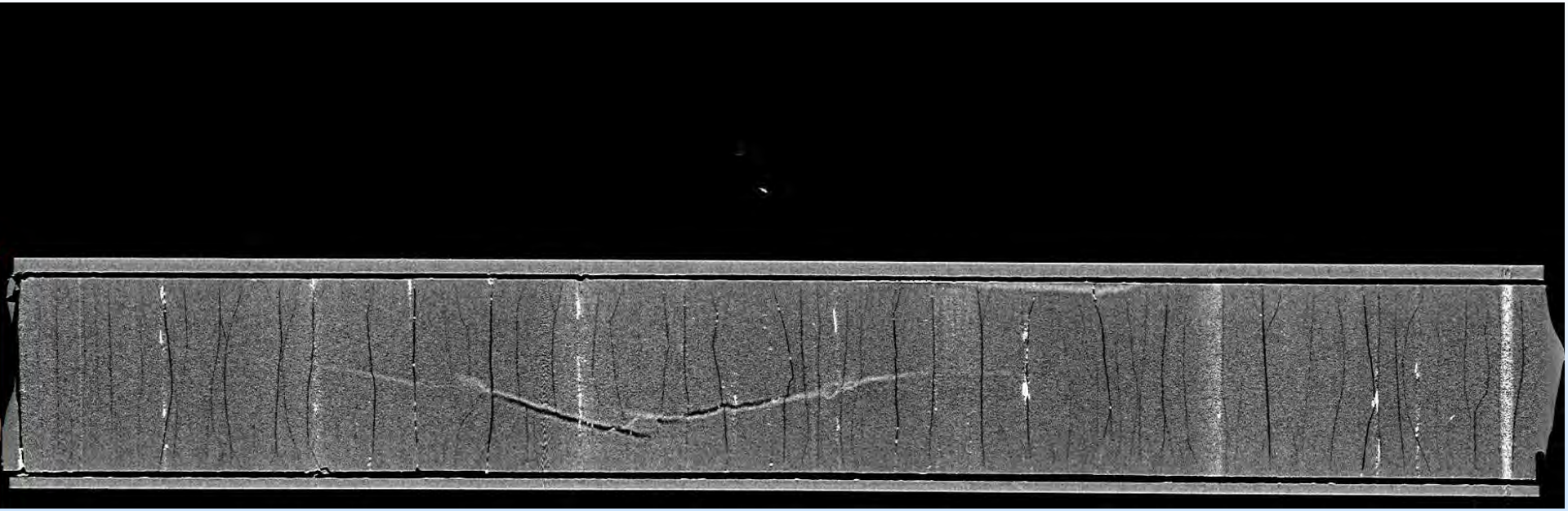
Progress to Date

- Data and Sample Collection
  - Cooperating groups required to provide results to MSEEL
  - Data Moved to Publically Accessible System on MSEEL.ORG and NETL-EDX
  - Selected data as Interactive Displays on MSEEL.ORG website
  - Core Archived at NETL Morgantown
- Integration of Data Ongoing
  - SPE HFC, AGU, AAPG Presentations
  - Numerous Publications – e.g., Interpretation PNAS, SPE
  - Migration of publicly available data to NETL EDX
  - Patent Applications (Fibpro) ➔ Commercialization
- Documentation of Entire Well Process
- Ability to Engineer Improved Completions

MSEEL Publications & Presentations Well Over 75

- American Association of Petroleum Geologists
- Society Of Petroleum Engineers
- Society of Exploration Geophysicists
- Geological Society of America
- American Society of Civil Engineers
- American Chemical Society
- American Petroleum Institute
- US Department of State
- US Energy Information Agency
- US Gas Power Conference
- Marcellus Shale Coalition
- Gas Technology Institute
- North American Coalbed Methane Forum

It all Begins with the Rock



CT scan from 3 ft. long section of the Marcellus starting at 7507’
110’ Whole Core from 3H, and 197 Sidewall Cores from 3H and SW

Dustin Crandall

Core Distribution - Institutions

- Oklahoma State Univ.
- Univ. Texas at Austin
- Stanford Univ.
- Cornell Univ.
- Texas A&M
- University of Virginia
- Colorado School of Mines
- Vermont
- Ohio State
- West Virginia University
- LBNL
- LANL (2 projects)
- SLAC
- Sandia
- NETL (3 groups)

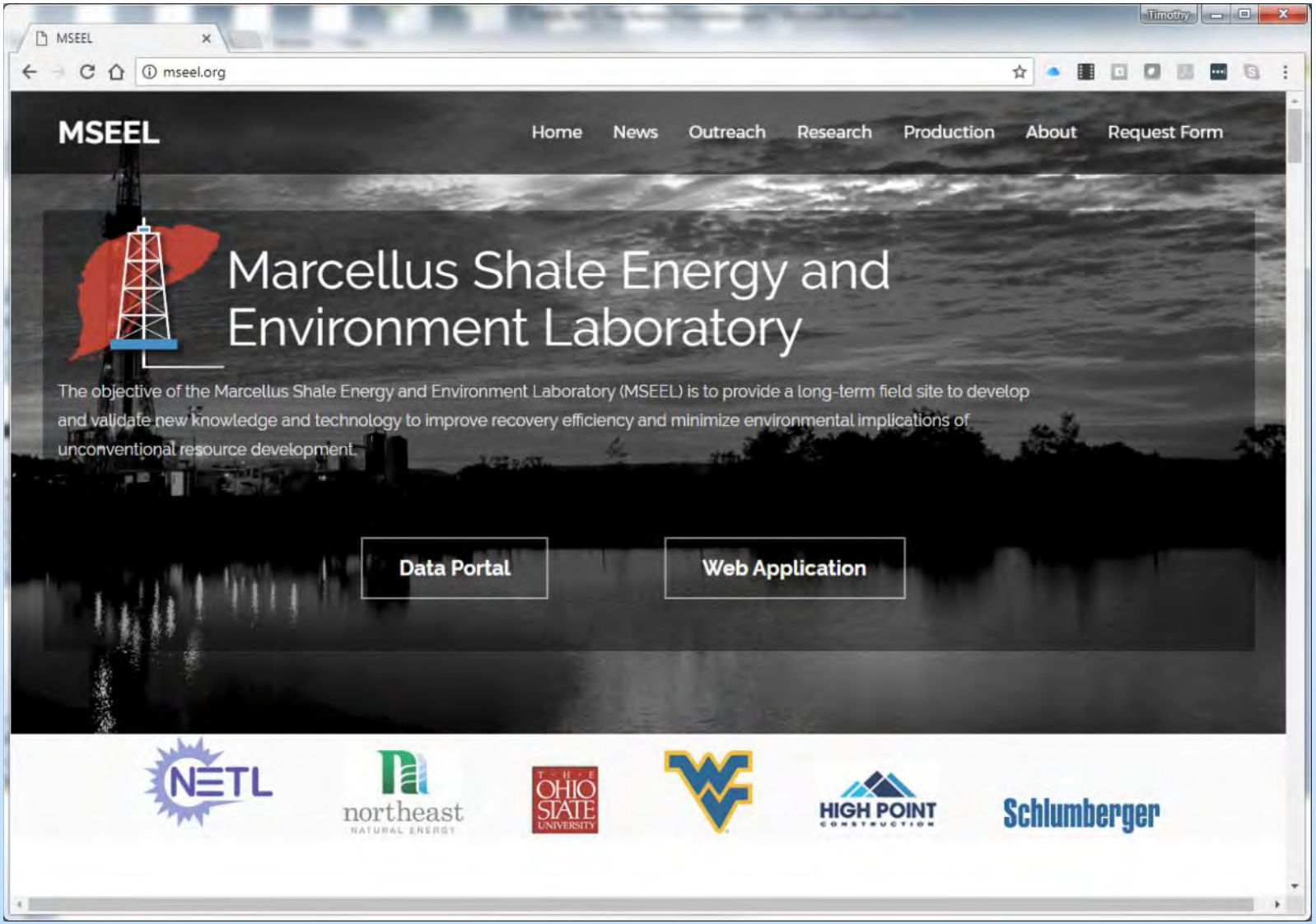
Core Distribution - Research Topics

- Core characterization and pore isolation
  - FIB-SEM
  - Bulk CT
  - Core logging with XRF
- Geochemical analysis of fracturing fluid alteration of shale matrix
  - Small scale synchrotron
  - Core scale fracture flow
- Geochemical leaching studies
- Evolutional diagenesis studies
- Brine/CO_2 contact angle measurements
- Proppant embedment studies

Fluids and Gas Distribution - Institutions

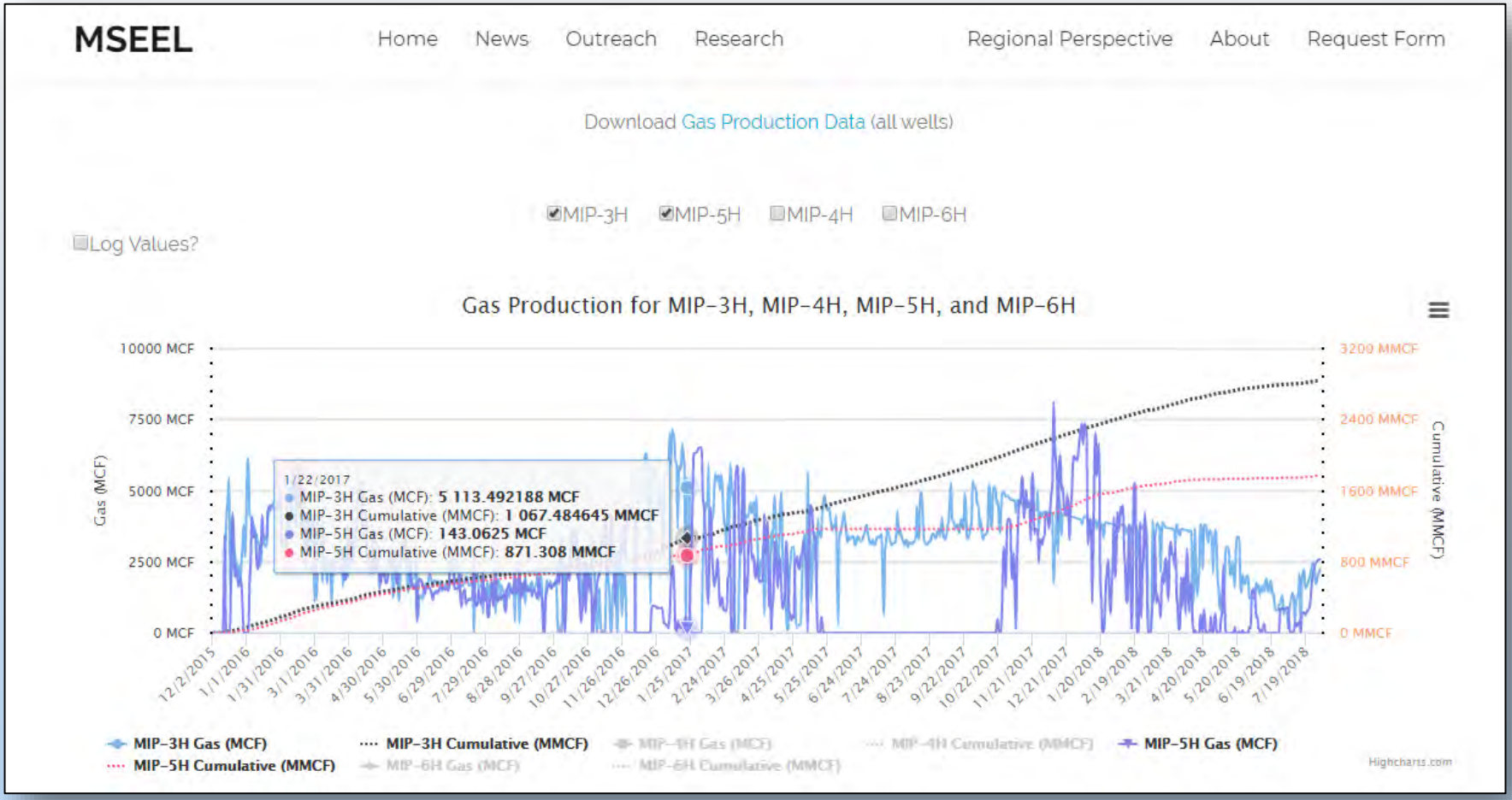
- USGS
- Cornell University
- University of Maryland
- Stevens Institute of Technology
- Ohio State University
- West Virginia University
- NETL (Multiple Groups)

Data Dissemination and Tech Transfer

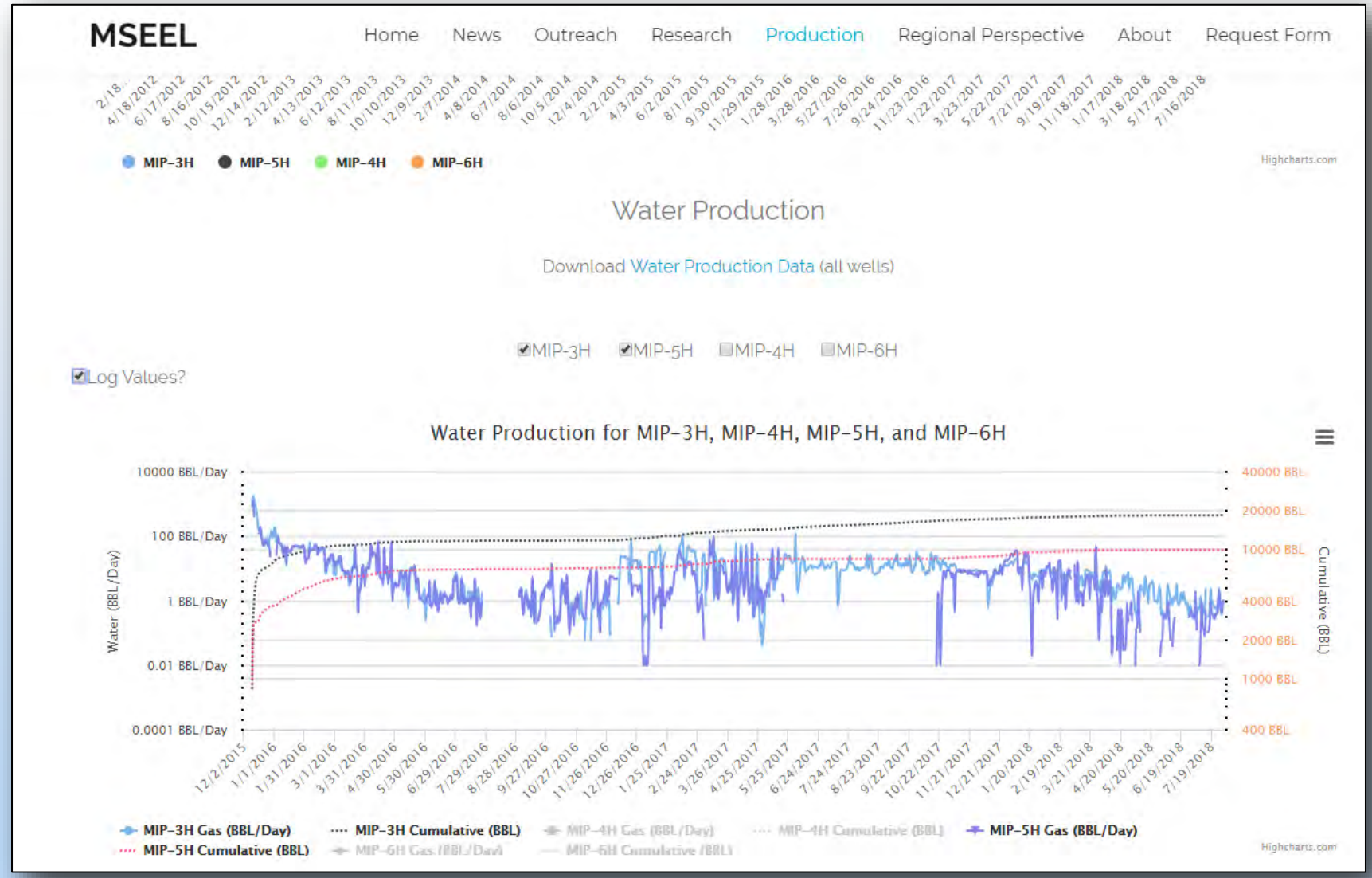


Creating Interactivity on MSEEL.ORG

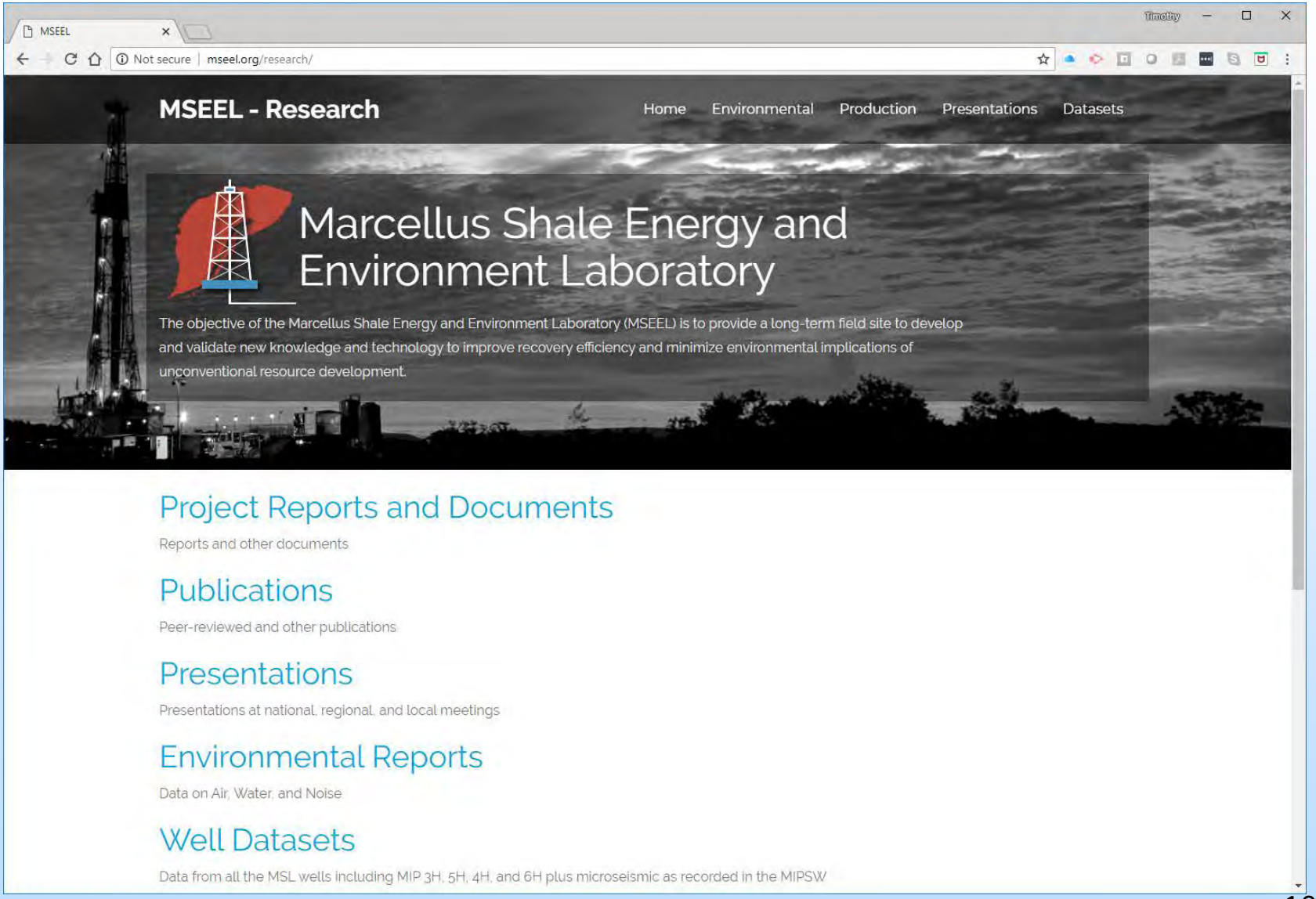
MSEEL – Gas Production



MSEEL Water Production



Data Dissemination and Tech Transfer



Tours and Student Instruction

MSEEL has had a significant outreach component with a number of students in petroleum engineering and geology using MSEEL in classes as class and capstone projects. Students have toured the MSEEL site during various stages of operations. Estimated numbers of students at over 100. Also numerous tours (~25) for interested domestic and foreign delegations with numbers of over 250.

Task Objectives
Liquid & Solid Wastes

- Characterize liquid and solid wastes
  - Makeup water
    - Inorganics, organics, radiochemistry
  - Hydraulic fracturing fluid
    - Injected volume
    - Chemistry
      - Inorganics, organics, radiochemistry
  - Produced water
    - Time series changes in produced water generation
    - Time series changes in produced water chemistry
      - Inorganics, organics, radiochemistry
  - Solid wastes
    - Drill cuttings
      - TCLP inorganics and organics
      - Radiochemistry
      - Effect of drilling fluid

Task Objectives
Alternative Fuels, Engines, and Emissions

- Assess the impacts of dual fuel and dedicated natural gas engines powering the prime movers of unconventional well development.
  - Regulated emissions, efficiency, fuel consumption, GHGs, costs, etc.

- Assess the temporal methane emissions of an active well pad
  - Compare highly accurate temporal results to establish methane emissions (efficiency) of production

Task Objectives
Deep Subsurface Geochemistry

- Understand the effect of hydraulic fracturing on microbial life
- Effect of microbial changes on well performance
  - Souring, fracture and pore clogging
  - Can production be enhanced with microbes
- Document changes in reservoir chemistry change during flowback.
- Document changes in fluid/gas flow pathways during flowback and hydrocarbon production.

Biogeochemical Characterization of Core, Fluids, and Gas

Isotopic/molecular/microbial characterization of core

WVU - Sharma ; OSU - Mouser, Wrighton, Wilkins, Cole, Darrah

Isotopic/molecular/microbial characterization of produced fluids

WVU - Sharma ; OSU - Mouser, Wrighton, Wilkins, Cole, Darrah

NETL - Hakala, Phan

Molecular characterization of produced gas

WVU - Sharma ; OSU - Darrah

S. Sharma

A. Hakala

P. Mouser

K. Wrighton

D. Cole

M. Wilkins

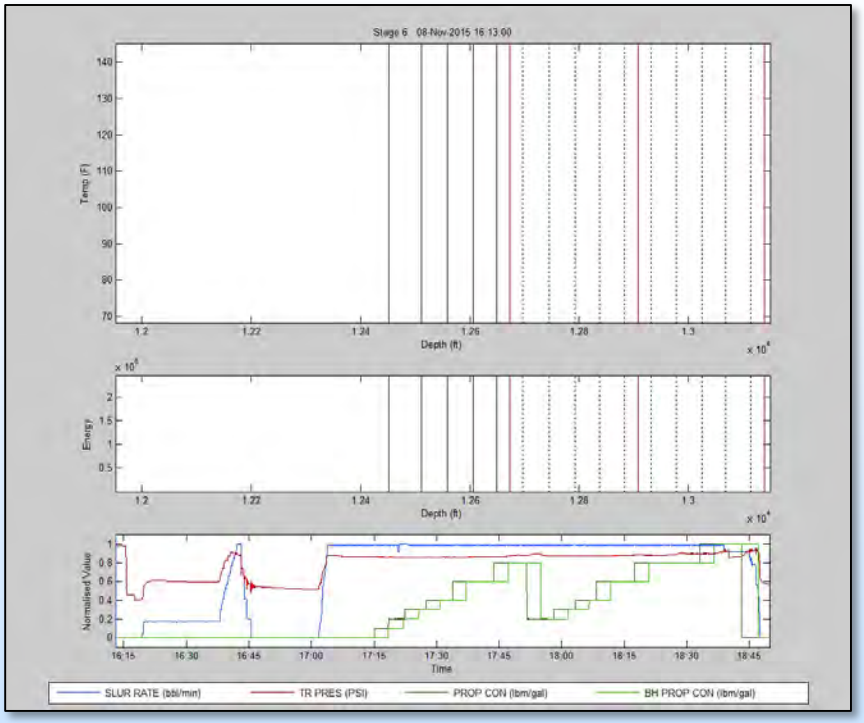
T. Darrah

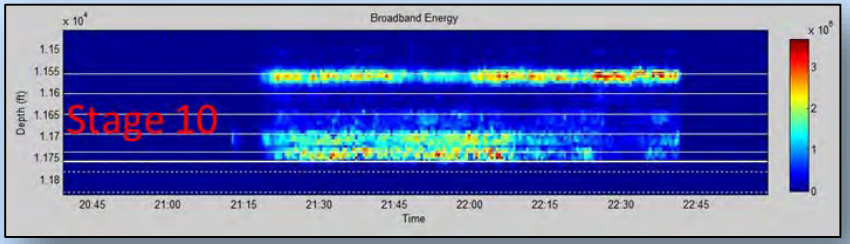
Task Objectives
Reservoir Characterization

- Improve our understanding of the Marcellus Shale reservoir system and shale reservoir systems in general as complex geologic entities
- Develop tools to improve assimilate and analyze large multiple terabyte datasets (volume, velocity and variety).
- Improve completion efficiency and ultimately production efficiency along the lateral.
- Provide and demonstrate potentially cost-effective technologies through MSEEL.
- Provide results that can be utilized as a guide to optimize the drilling and hydraulic fracturing design parameters for new wells.

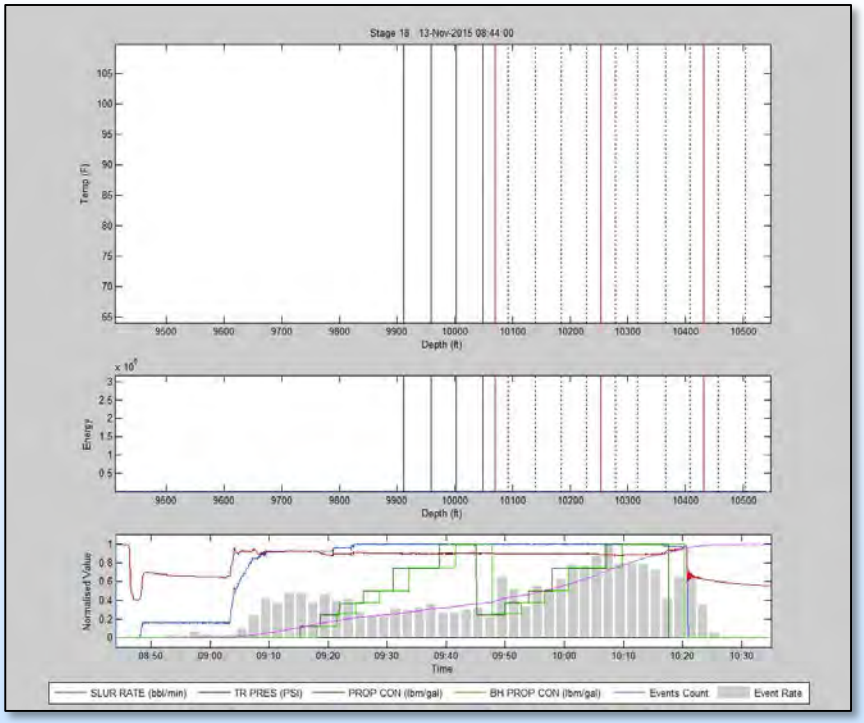
Integrated Analysis Leads to Specific Understanding

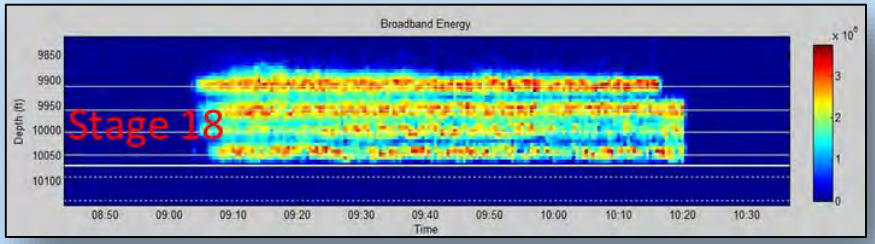
Poor cluster efficiency, stage screened out and ended prior to putting away sand loading as designed



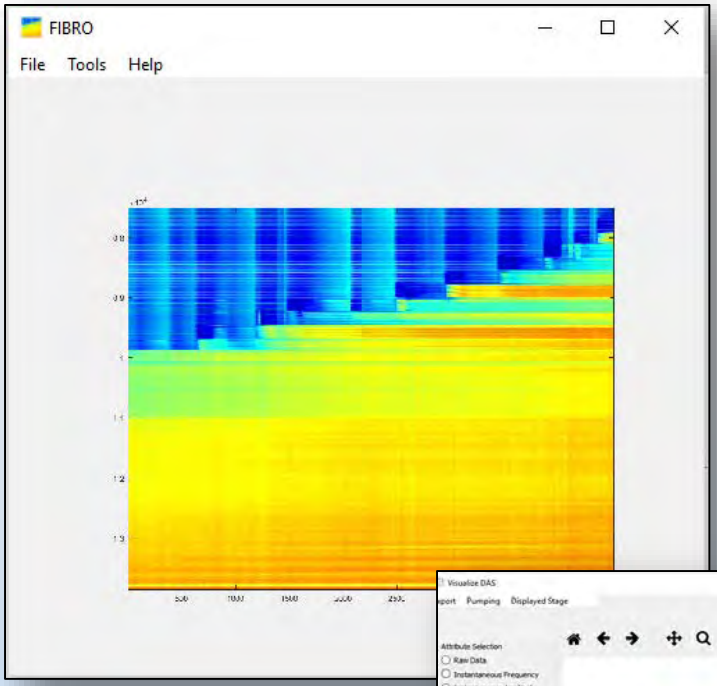


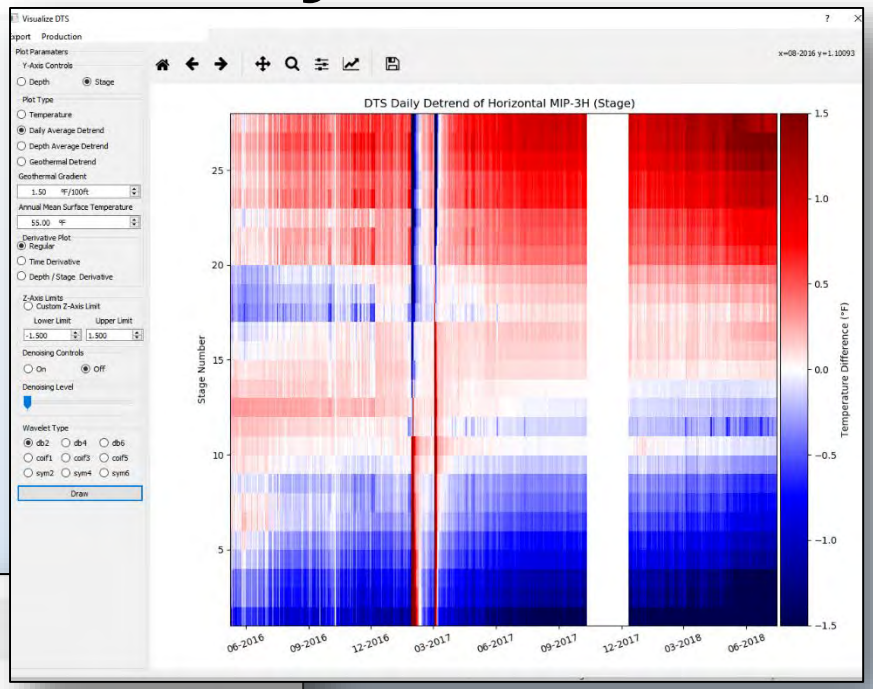
Good cluster efficiency, and the Engineered stage design was completed per design

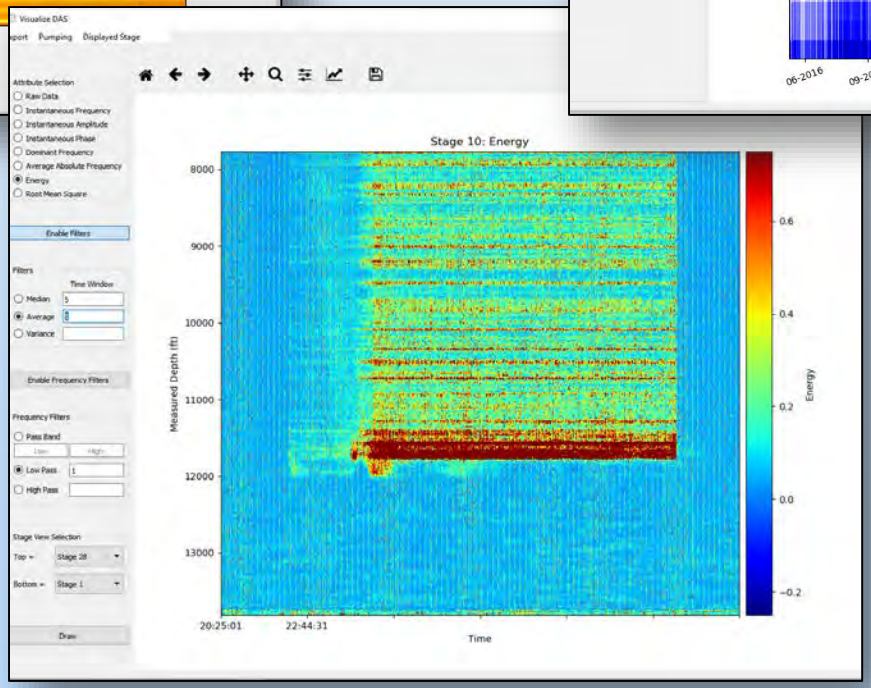




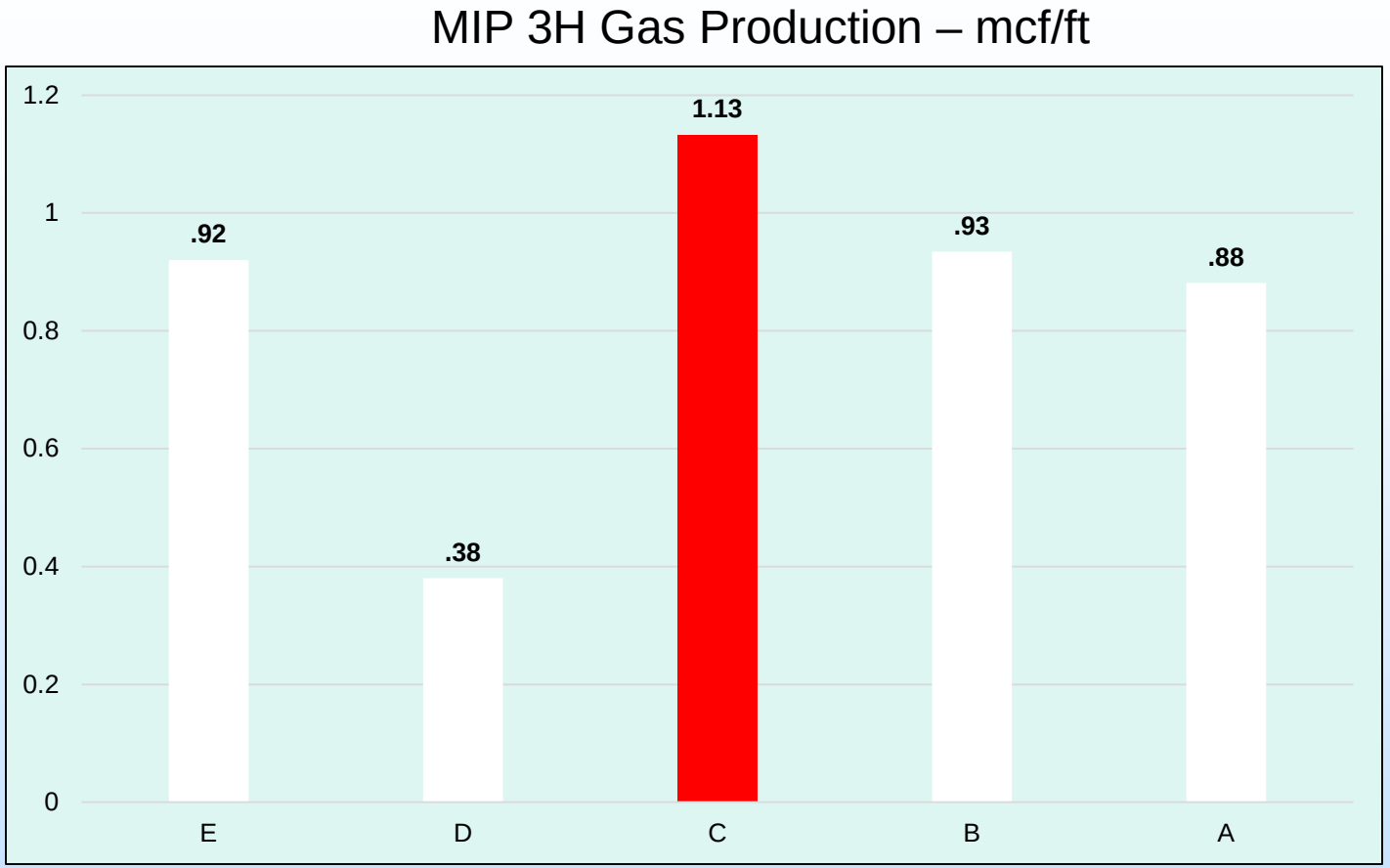
Processing Terabytes







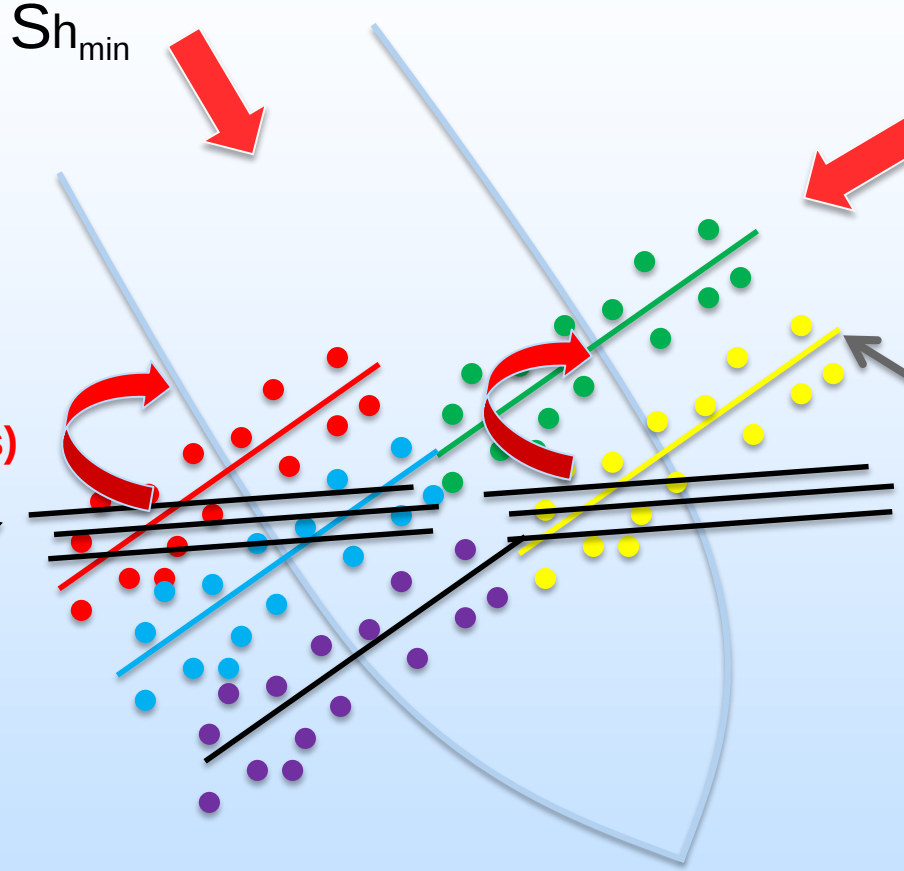
Results = Future Productivity Increase



- Engineered design using data obtained during MSEEL has ~20% increased production compared to standard NNE completion techniques
- EUR for future wells could be ~10-20% greater ***IF*** we can exploit the technologic advantages gained through MSEEL in a more cost-effective fashion

SURFACE MONITORING OF SLOW SLIP (LPLD)

Synopsis of slow-slip deformation



Adapted from Zoback et al., 2012

Significant Project Accomplishments

- By being able to gather, assimilate, and analyze information such as core (whole and sidewall), extensive open-hole logging suites (in both vertical and horizontal), fiber optic data, production logs, microseismic data, etc. from one site and two(three) wells, we have been able to gain a better understanding of the Marcellus shale reservoir system in its entirety

- By being able to obtain detailed environmental data and analysis, the project has proven that by using a best practices approach to shale development, the industry can extract shale gas safely, efficiently, while minimizing environmental impact

- Through the continual integration of all of these data, we have also learned that we are not done learning. Several questions have been answered while several others need more quantification. Of course, new ideas and hypotheses have also arisen as a result of the MSEEL project

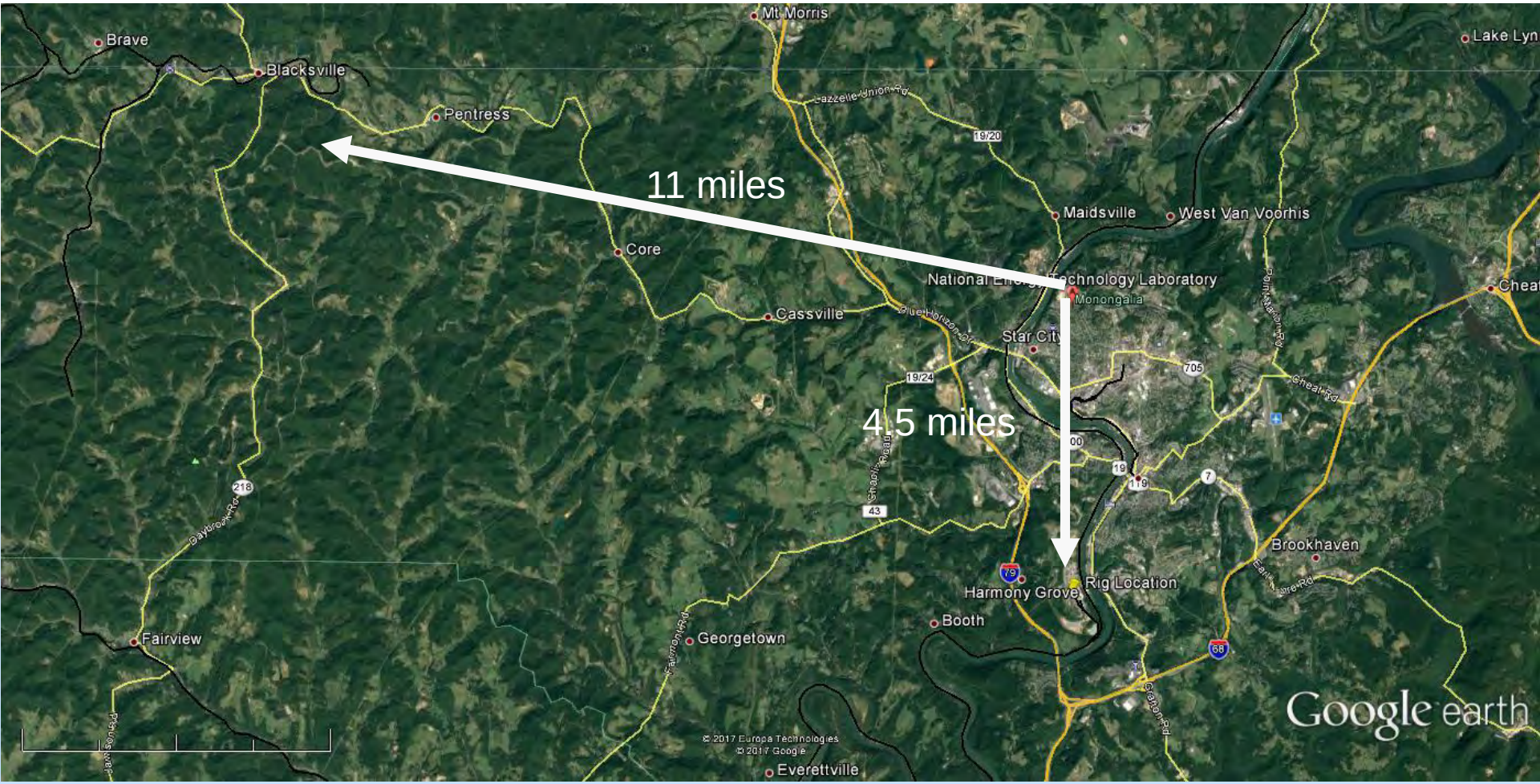
Remaining Technical Gaps/Challenges

- Obtained a lot of core data
  - Need to better understand porosity/permeability relationships
  - Need stress/strain/compressibility data from core to tie to geomechanical properties derived from log data
  - Can use core to tie to natural fractures and natural fractures to microseismic and microseismic to full reservoir model
- Still technology and knowledge gap on what we can measure and understand from fiber optic data
  - Lots (many TB) of data recorded and captured to date, but analysis tools are not readily available to the industry or researchers
  - Need to develop near real-time processing tools
- How do we undertake this type of analysis more cost-effectively so that we can gain this type of understanding more often?

Synergy Opportunities

- Well over 100 Researchers from Multiple Institutions are Involved in the MSEEL
- Provides a Template for other Field Projects
- Potential to Model CO2 Storage
- Understanding of Use of Fiber-Optic Data to Monitor Wells
- All Data is Publicly Available Online

Proposed MSEEL Phase 3 Site



Ample opportunities and interest by NNE to drill and complete another well in association with the MSEEL project

MSEEL Plans

- How do we undertake this type of analysis more cost-effectively so that we can gain this type of understanding more often?
- “How can one leverage this improved understanding gained through MSEEL to drill better wells?”
  - More gas extracted, minimal disturbance, similar/lower costs
- Advances over the past two years to allow us to move from test well projects to being able to employ these or similar technologies in a development scenario
  - More cost-effective techniques to better leverage technologies
- Test next generation technologies in an area with previous drilling to determine feasibility of applying lessons learned on an “every well” basis to determine if we can get more gas from each well
  - Allow for models to be created from different (cheaper) data sets that can be deployed in a near real-time development scenario
  - Some questions – Are there as many fractures and similar orientation? How do rock properties compare to MIP? Why is production better?

Potential Next Phase Technologies

- Full wellbore and sidewall cores
  - Will be “ground truth” for geomechanical data and logs listed below
- Fracture ID
  - Drillbit geomechanics to determine “fracability” of every few inches along wellbore
  - Eliminates need for some costly horizontal open hole logging – need to correlate to core
- PetroMar FracView
  - Behind bit borehole imaging tool
  - Provides similar picture of natural fracture network intersecting wellbore
  - Will add data points for locating perfs and aid in understanding natural fracture network for modeling drainage patterns, frac efficiency, etc.
- Full Vertical Pilot Logging Suite (SLB)
  - Will tie remainder of field and region to detailed, well specific information
- Surface microseismic
  - Better surface conditions here to obtain data
  - Will be used for multiple wells and frac jobs to look at well to well influence and dependency
- Full well cuttings analysis
  - XRD/XRF to tie to drillbit geomechanics and core analysis
- Tracer technology
  - Used to compare stage to stage communication via proppant and fluid
  - Can be tied to microseismic data and fiber
- Sliding sleeve Frac
  - Can control fluid/sand each cluster received to make sure they are all being fractured effectively
  - Should be great tie in with fiber
- Fiber Optics DAS
  - Not only used for frac efficiency tie, but also possibly for microseismic during drilling/frac of offset wells
  - Continued improvement to analysis software through Academic consortium

Building Partnerships for Research, Education, and Outreach

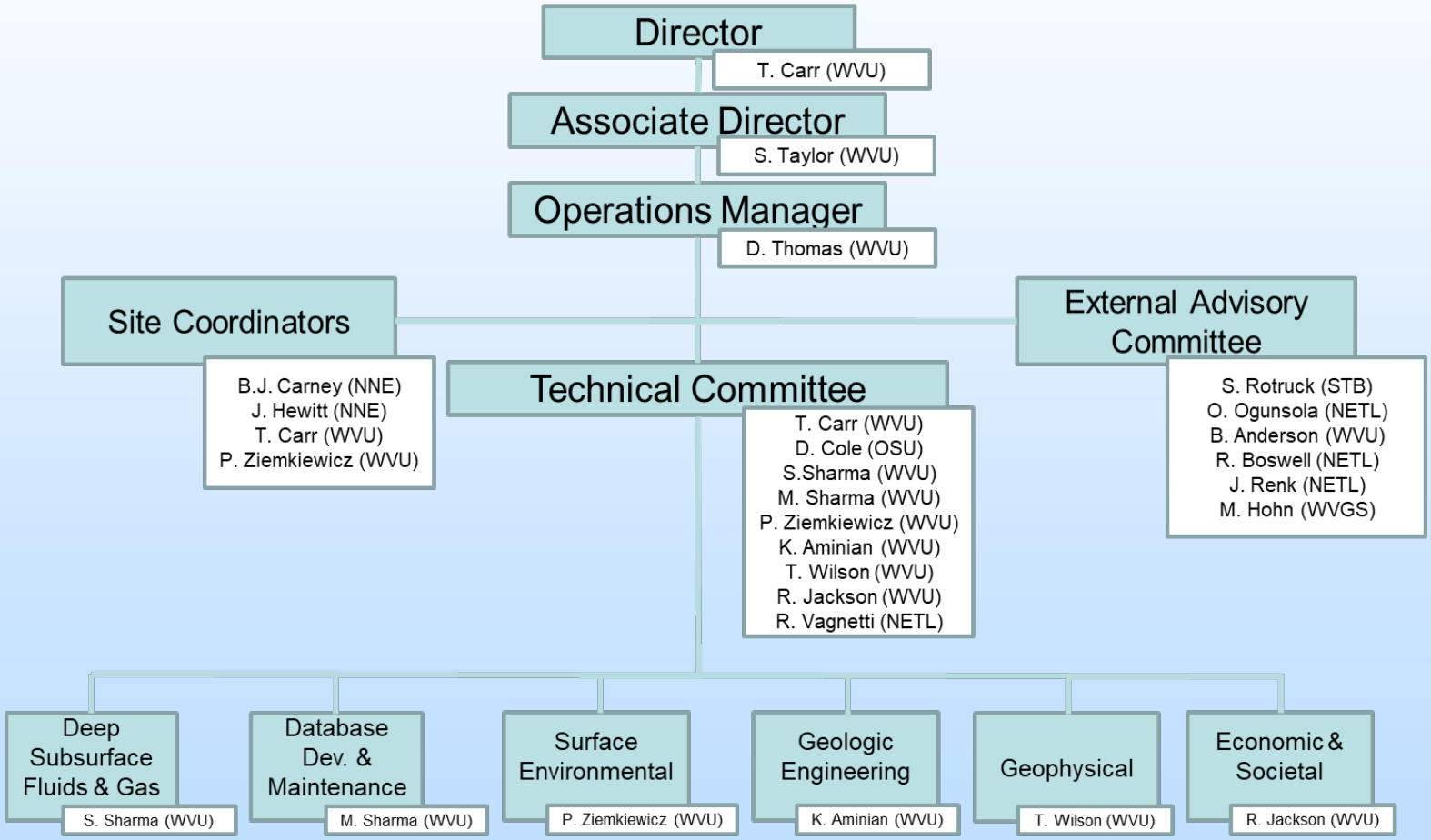
This research was funded by a grant from Department of Energy's National Energy Technology Laboratory and the Department of State

West Virginia University
MSEEL
Marcellus Shale Energy & Environment Laboratory
Northeast Natural Energy

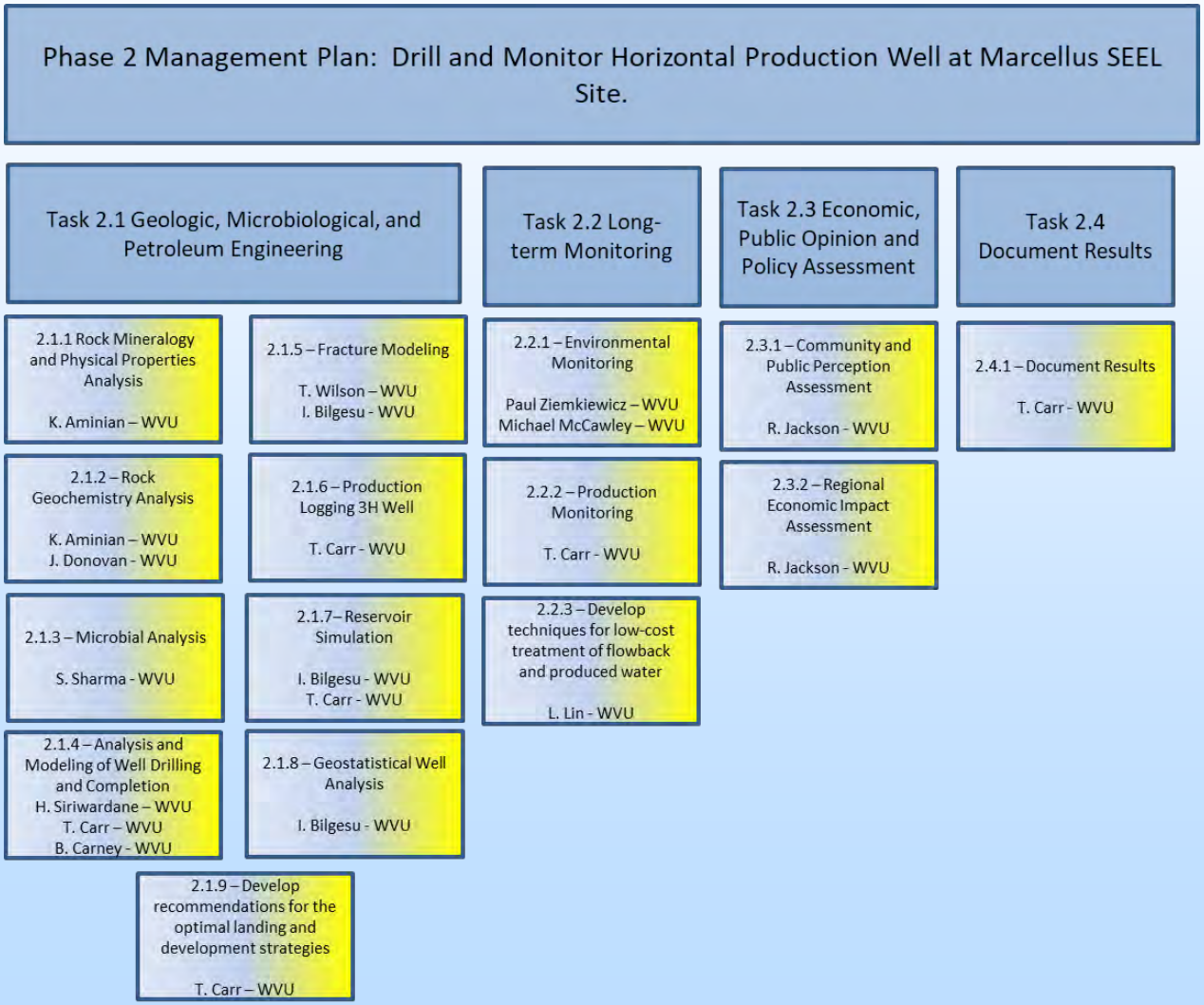
Appendix

– These slides will not be discussed during the presentation, but are mandatory

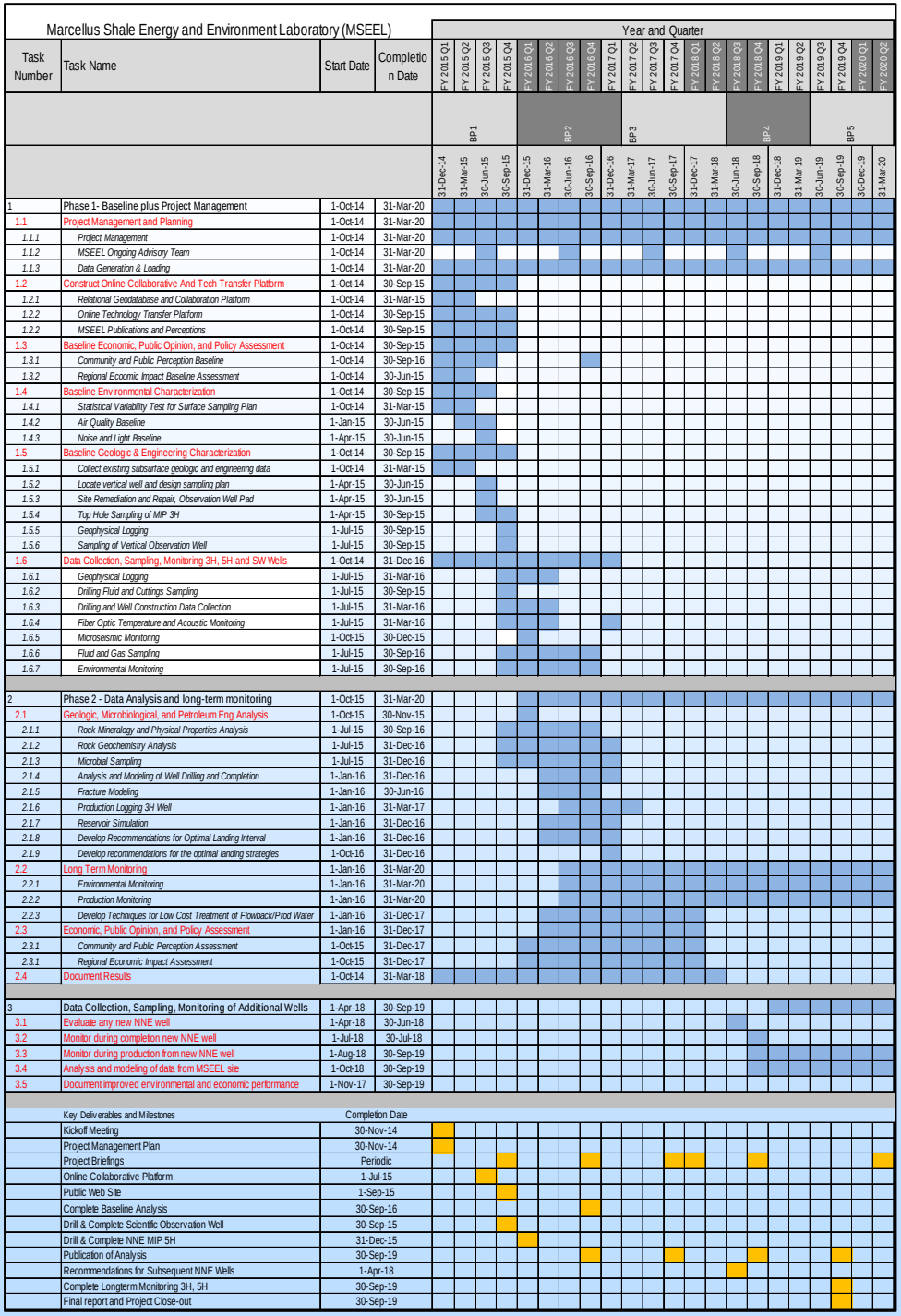
Organization Chart



Organization Chart



Gantt Chart


Marcellus Shale Energy and Environment Laboratory (MSEEL)
Year and Quarter
Task Number
Task Name
Start Date
Completion Date
FY 2015 Q1
FY 2015 Q2
FY 2015 Q3
FY 2015 Q4
FY 2016 Q1
FY 2016 Q2
FY 2016 Q3
FY 2016 Q4
FY 2017 Q1
FY 2017 Q2
FY 2017 Q3
FY 2017 Q4
FY 2018 Q1
FY 2018 Q2
FY 2018 Q3
FY 2018 Q4
FY 2019 Q1
FY 2019 Q2
FY 2019 Q3
FY 2019 Q4
FY 2020 Q1
FY 2020 Q2
BP1
BP2
BP3
BP4
BP5
31-Dec-14
31-Mar-15
30-Jun-15
30-Sep-15
31-Dec-15
31-Mar-16
30-Jun-16
30-Sep-16
31-Dec-16
31-Mar-17
30-Jun-17
30-Sep-17
31-Dec-17
31-Mar-18
30-Jun-18
30-Sep-18
31-Dec-18
31-Mar-19
30-Jun-19
30-Sep-19
30-Dec-19
31-Mar-20
1 Phase 1- Baseline plus Project Management 1-Oct-14 31-Mar-20
1.1 Project Management and Planning 1-Oct-14 31-Mar-20
1.1.1 Project Management 1-Oct-14 31-Mar-20
1.1.2 MSEEL Ongoing Advisory Team 1-Oct-14 31-Mar-20
1.1.3 Data Generation & Loading 1-Oct-14 31-Mar-20
1.2 Construct Online Collaborative And Tech Transfer Platform 1-Oct-14 30-Sep-15
1.2.1 Relational Geodatabase and Collaboration Platform 1-Oct-14 31-Mar-15
1.2.2 Online Technology Transfer Platform 1-Oct-14 30-Sep-15
1.2.2 MSEEL Publications and Perceptions 1-Oct-14 30-Sep-15
1.3 Baseline Economic, Public Opinion, and Policy Assessment 1-Oct-14 30-Sep-15
1.3.1 Community and Public Perception Baseline 1-Oct-14 30-Sep-16
1.3.2 Regional Ecoomic Impact Baseline Assessment 1-Oct-14 30-Jun-15
1.4 Baseline Environmental Characterization 1-Oct-14 30-Sep-15
1.4.1 Statistical Variability Test for Surface Sampling Plan 1-Oct-14 31-Mar-15
1.4.2 Air Quality Baseline 1-Jan-15 30-Jun-15
1.4.3 Noise and Light Baseline 1-Apr-15 30-Jun-15
1.5 Baseline Geologic & Engineering Characterization 1-Oct-14 30-Sep-15
1.5.1 Collect existing subsurface geologic and engineering data 1-Oct-14 31-Mar-15
1.5.2 Locate vertical well and design sampling plan 1-Apr-15 30-Jun-15
1.5.3 Site Remediation and Repair, Observation Well Pad 1-Apr-15 30-Jun-15
1.5.4 Top Hole Sampling of MIP 3H 1-Apr-15 30-Sep-15
1.5.5 Geophysical Logging 1-Jul-15 30-Sep-15
1.5.6 Sampling of Vertical Observation Well 1-Jul-15 30-Sep-15
1.6 Data Collection, Sampling, Monitoring 3H, 5H and SW Wells 1-Oct-14 31-Dec-16
1.6.1 Geophysical Logging 1-Jul-15 31-Mar-16
1.6.2 Drilling Fluid and Cuttings Sampling 1-Jul-15 30-Sep-15
1.6.3 Drilling and Well Construction Data Collection 1-Jul-15 31-Mar-16
1.6.4 Fiber Optic Temperature and Acoustic Monitoring 1-Jul-15 31-Mar-16
1.6.5 Microseismic Monitoring 1-Oct-15 30-Dec-15
1.6.6 Fluid and Gas Sampling 1-Jul-15 30-Sep-16
1.6.7 Environmental Monitoring 1-Jul-15 30-Sep-16
2 Phase 2 - Data Analysis and long-term monitoring 1-Oct-15 31-Mar-20
2.1 Geologic, Microbiological, and Petroleum Eng Analysis 1-Oct-15 30-Nov-15
2.1.1 Rock Mineralogy and Physical Properties Analysis 1-Jul-15 30-Sep-16
2.1.2 Rock Geochemistry Analysis 1-Jul-15 31-Dec-16
2.1.3 Microbial Sampling 1-Jul-15 31-Dec-16
2.1.4 Analysis and Modeling of Well Drilling and Completion 1-Jan-16 31-Dec-16
2.1.5 Fracture Modeling 1-Jan-16 30-Jun-16
2.1.6 Production Logging 3H Well 1-Jan-16 31-Mar-17
2.1.7 Reservoir Simulation 1-Jan-16 31-Dec-16
2.1.8 Develop Recommendations for Optimal Landing Interval 1-Jan-16 31-Dec-16
2.1.9 Develop recommendations for the optimal landing strategies 1-Oct-16 31-Dec-16
2.2 Long Term Monitoring 1-Jan-16 31-Mar-20
2.2.1 Environmental Monitoring 1-Jan-16 31-Mar-20
2.2.2 Production Monitoring 1-Jan-16 31-Mar-20
2.2.3 Develop Techniques for Low Cost Treatment of Flowback/Prod Water 1-Jan-16 31-Dec-17
2.3 Economic, Public Opinion, and Policy Assessment 1-Jan-16 31-Dec-17
2.3.1 Community and Public Perception Assessment 1-Oct-15 31-Dec-17
2.3.1 Regional Economic Impact Assessment 1-Oct-15 31-Dec-17
2.4 Document Results 1-Oct-14 31-Mar-18
3 Data Collection, Sampling, Monitoring of Additional Wells 1-Apr-18 30-Sep-19
3.1 Evaluate any new NNE well 1-Apr-18 30-Jun-18
3.2 Monitor during completion new NNE well 1-Jul-18 30-Jul-18
3.3 Monitor during production from new NNE well 1-Aug-18 30-Sep-19
3.4 Analysis and modeling of data from MSEEL site 1-Oct-18 30-Sep-19
3.5 Document improved environmental and economic performance 1-Nov-17 30-Sep-19
Key Deliverables and Milestones
Completion Date
Kickoff Meeting 30-Nov-14
Project Management Plan 30-Nov-14
Project Briefings Periodic
Online Collaborative Platform 1-Jul-15
Public Web Site 1-Sep-15
Complete Baseline Analysis 30-Sep-16
Drill & Complete Scientific Observation Well 30-Sep-15
Drill & Complete NNE MIP 5H 31-Dec-15
Publication of Analysis 30-Sep-19
Recommendations for Subsequent NNE Wells 1-Apr-18
Complete Longterm Monitoring 3H, 5H 30-Sep-19
Final report and Project Close-out 30-Sep-19

Bibliography

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5. Akondi R, Sharma S, Trexler R, Mouser PJ, Pfiffner SM, 2018. Microbial Lipid Biomarkers Detected in Deep Subsurface Black Shales Geomicrobiology (in review)
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