Laser Manipulation of Fracture Systems for Carbon Sequestration

Project Number: FWP 100249

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U.S. Department of Energy

National Energy Technology Laboratory

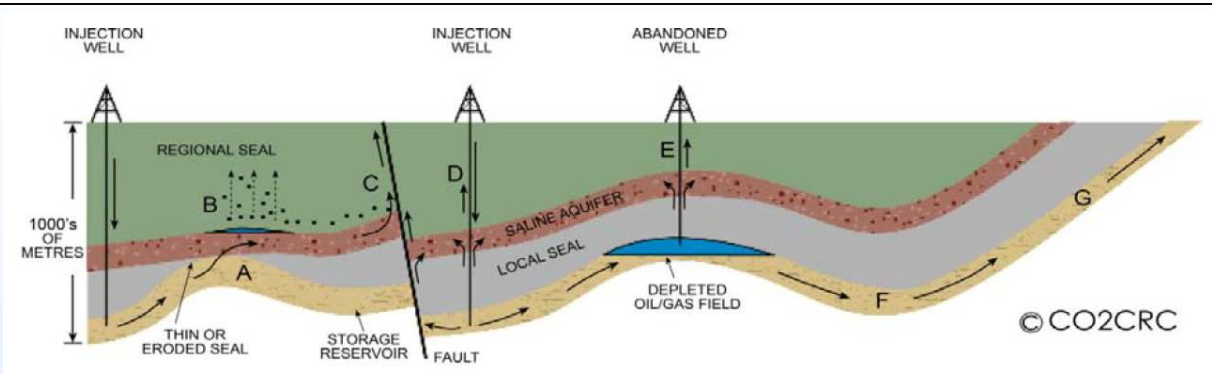
Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

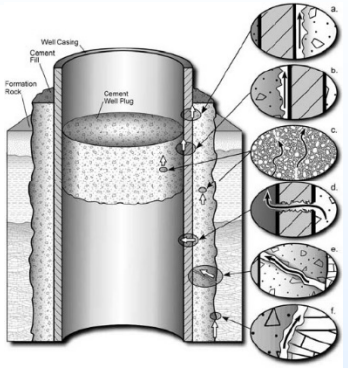
August 16-18, 2016

Presentation Outline

- Introduction and Project Overview
- Benefits to the Program
- Technical Status
  - Sample Preparation
  - Characterization Tools
- Synergy Opportunities
- Accomplishments to Date
- Summary

Project Overview:
Introduction





- Is it technically feasible to use lasers to precisely cut ***and*** weld shale?
- Potentially transformative nearfield down-bore technology
- SubTER pillar: Permeability Manipulation and Fluid Control
- Characterize morphological and chemical changes in shale as function of lithology and power

IEAGHG, "Caprock Systems for CO_2 Geological Storage", 2011/01, June, 2011.
M. A. Celia et al., "Modeling Critical Leakage Pathways in a Risk Assessment Framework: Representation of Abandoned Wells", Fourth Annual Conference on Carbon Capture and Sequestration DOE/NETL, May 2-5, 2005.

Project Overview:
SLAC-Foro Collaboration

- Foro: Innovator in downhole laser drilling
  - Transmit laser power miles through optical fibers
  - Reducing stimulated Brillouin scattering
  - Optical slip ring
- Foro has demonstrated laser cutting/drilling for installing and decommissioning wells
- SLAC: Advanced “4D” microstructural characterization

Project Overview:
Laser Material Removal

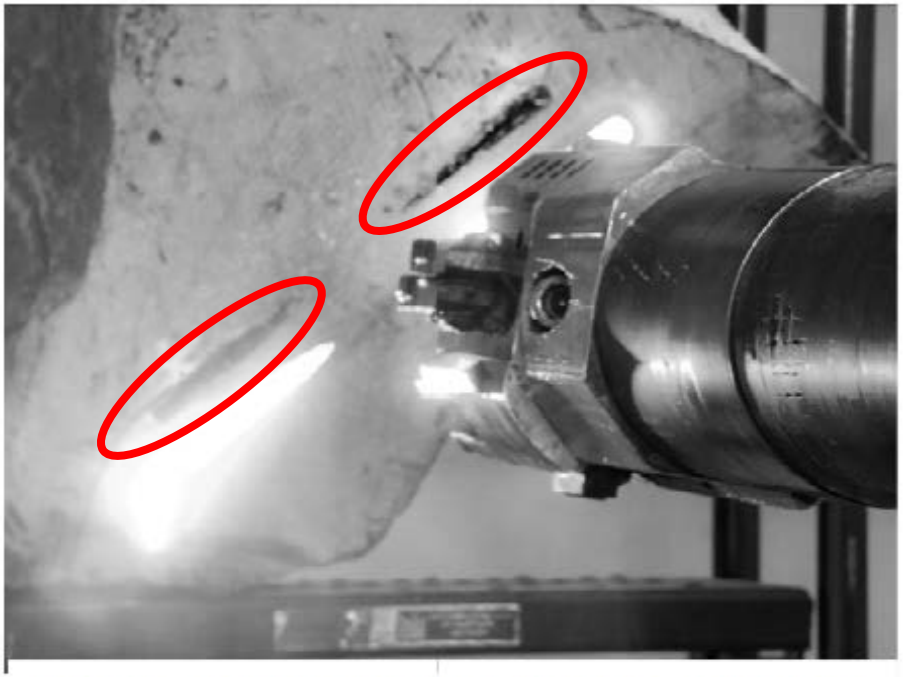


Figure 1. Foro Energy Drill bit combining high power laser energy with PDC bit technology.

M. S. Zediker, “High Power Fiber Lasers in Geothermal, Oil & Gas,” *Proc. Of SPIE* Vol. 8961, 89610D-1 (2014).

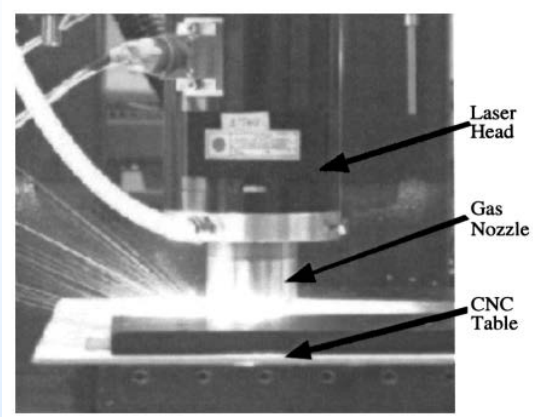
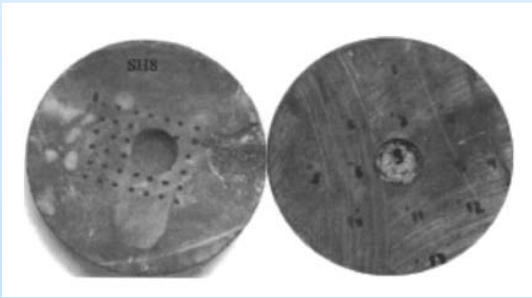
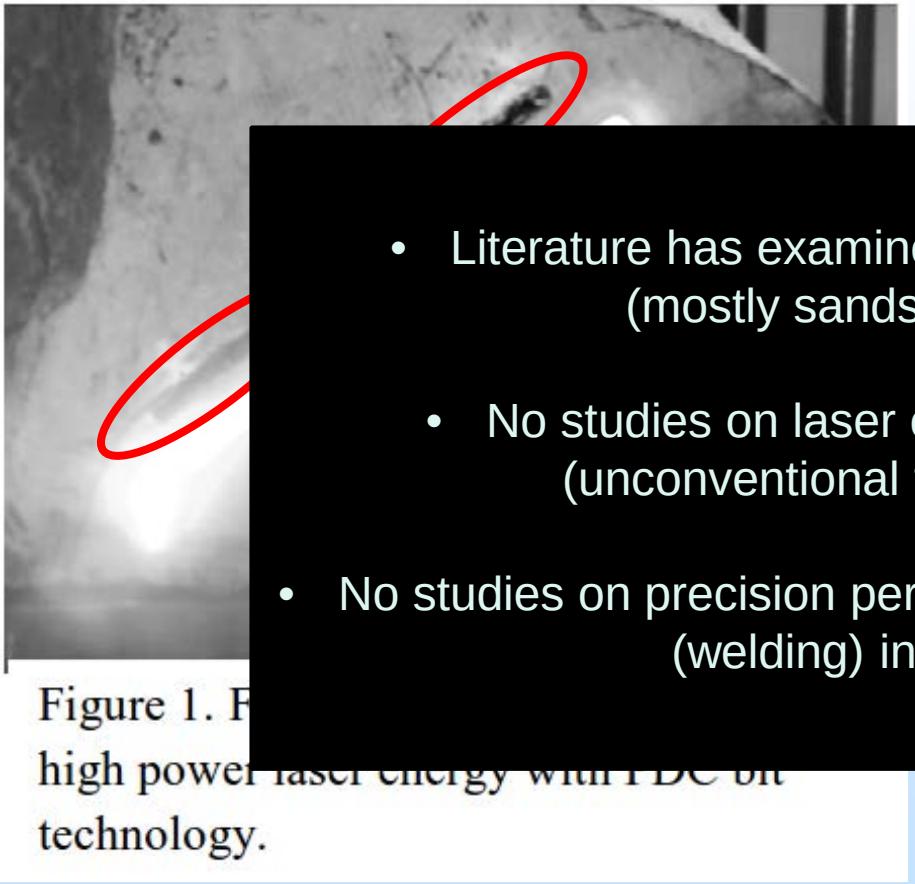


FIG. 1. Annotated photograph of the laser drilling system.

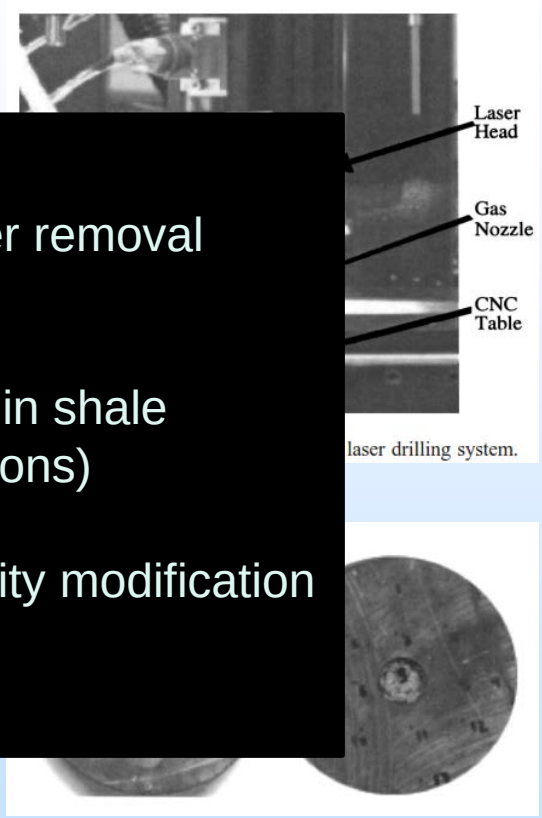


Z. Xu et al., “Specific energy for pulsed laser rock drilling,” *J. Laser App.*, **15**, 25 (2003).

Project Overview:
Laser Material Removal



- Literature has examined laser removal (mostly sandstone)
- No studies on laser cutting in shale (unconventional formations)
- No studies on precision permeability modification (welding) in shale

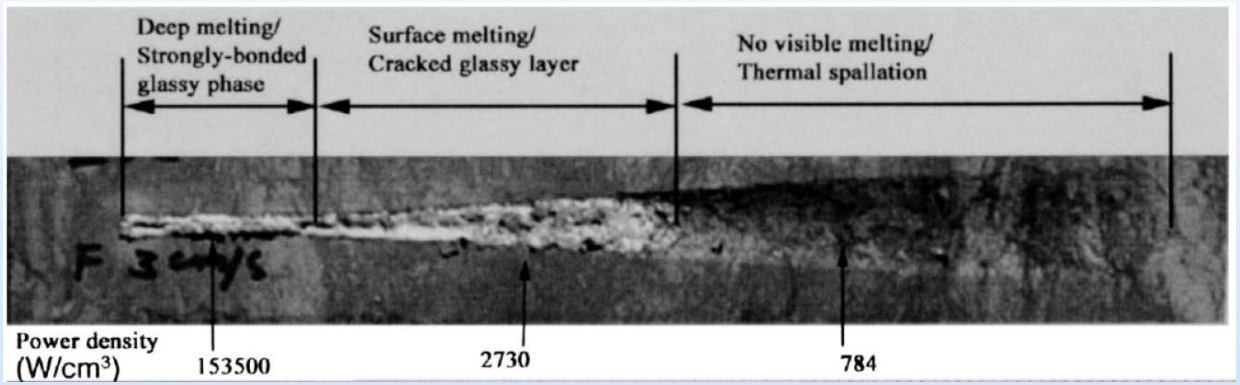


M. S. Zediker, "High Power Fiber Lasers in Geothermal, Oil & Gas," *Proc. Of SPIE* Vol. 8961, 89610D-1 (2014).

Z. Xu et al., "Specific energy for pulsed laser rock drilling," *J. Laser App.*, **15**, 25 (2003).

Project Overview:
Manipulating Permeability

- What does the laser exposure do to the rock?
- How does it affect the morphology?
- Is there an effect of mineralogy or geochemistry?



- Can laser exposure be used as a way of manipulating the rock permeability?

Z. Xu et al., "Specific energy for pulsed laser rock drilling," *J. Laser App.*, **15**, 25 (2003).

Project Overview:
Hypothesis

- **Hypothesis: Laser exposure can be used to modify rock microstructure in a controlled fashion**

- Consider changes in the morphology; contrasting shale composition
  - Mineralogy: Green River and Marcellus

- Use micro-CT and FIB-SEM to quantify local changes in porosity, permeability, and mineralogy

SLAC

Benefits to the Program

- Goal: Understand how laser fluence can affect microstructure and be used for tailoring properties such as permeability.

- Potentially transformative technology
- Using laser light, the morphology of the rock can be modified using a procedure that is
  - Localized
  - Well controlled
  - Specific to the mineralogy

Project Tasks

Project Management Plan

Experimental Plan

- Initial Characterization
- Laser Exposure
- Post-treatment Characterization

Publish Results

Project Start:
March 1, 2016

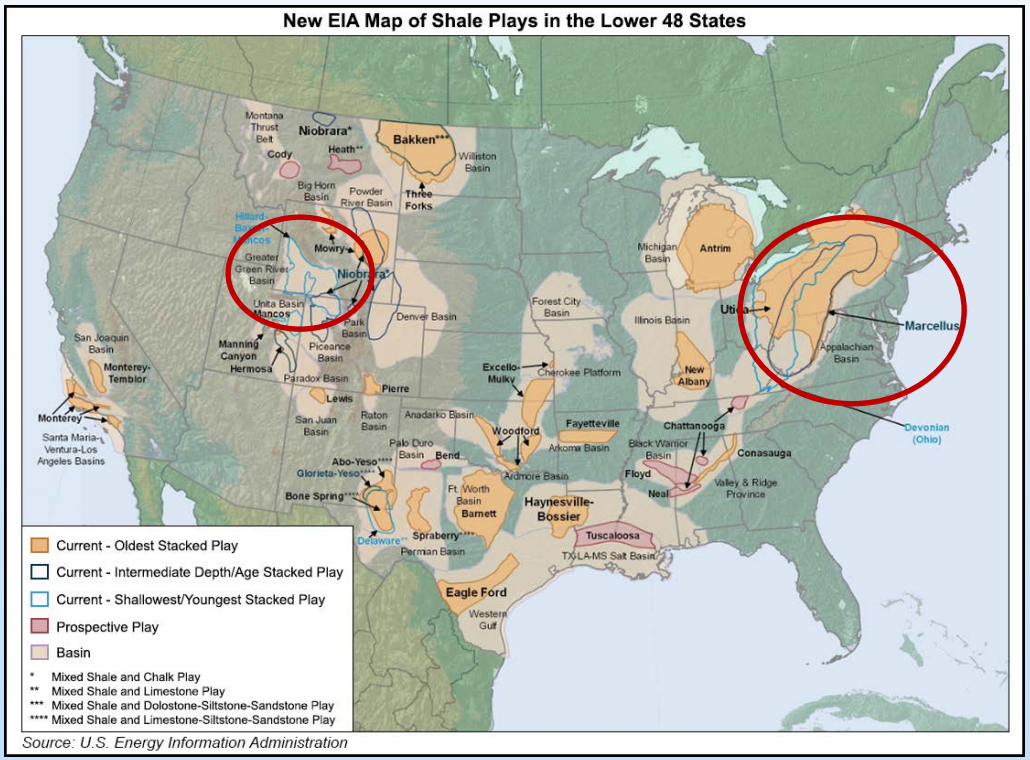
Technical Status:
Samples

Green River Shale

- High carbonate content

Marcellus Shale

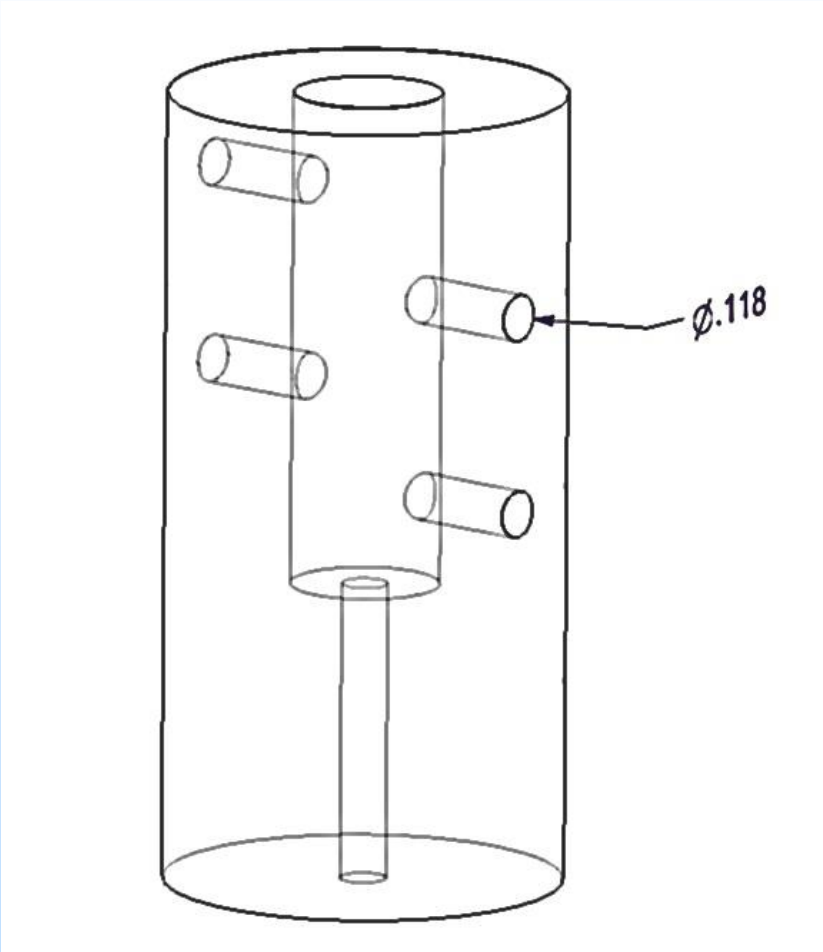
- High clay content



Source: U.S. Energy Information Administration

Technical Status:
Preparing Samples

- Green River and Marcellus shales
- 1.000 inch samples will be cored from collected source rock
- A 3/8 inch hole will be laser drilled
- 3 mm cores will be extracted to examine
  - Effect of depth along drilled hole
  - Changes along radius



Technical Status:
Laser Exposure

Laser Focused on Test Sample

Laser Firing 3kW on Sample

(4.2 kW cm^{-2})

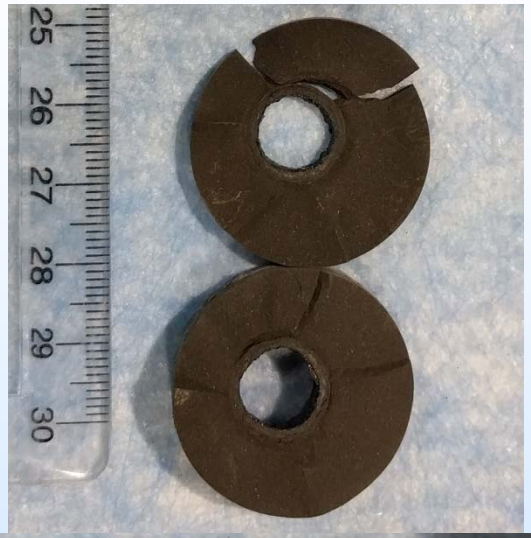
Lased Sample

Samples exposed between 4 to 12 s

Content from Foro Energy

Technical Status:
Laser Exposure

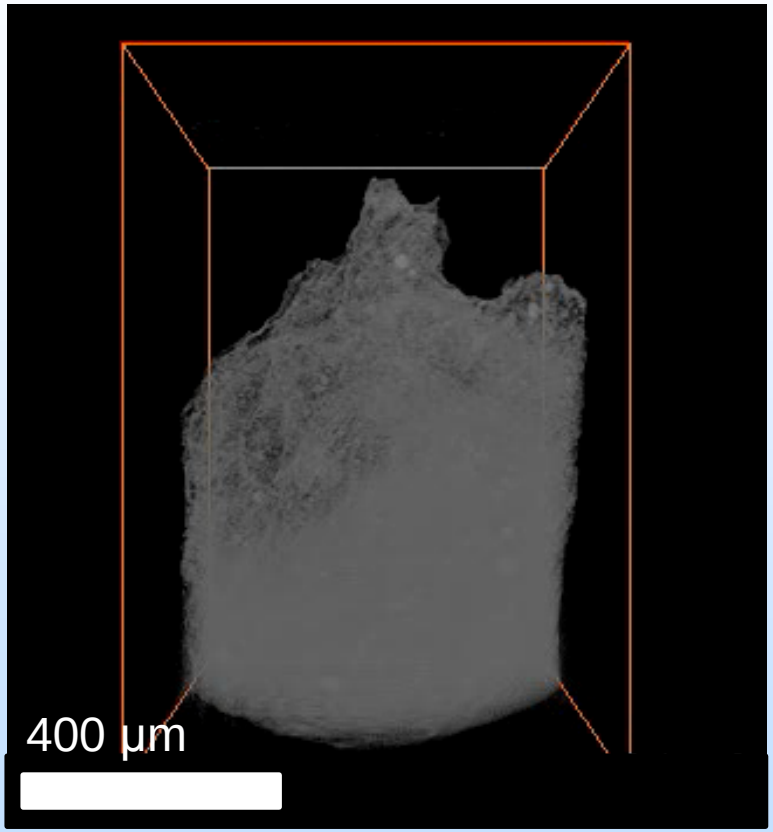
Marcellus Shale



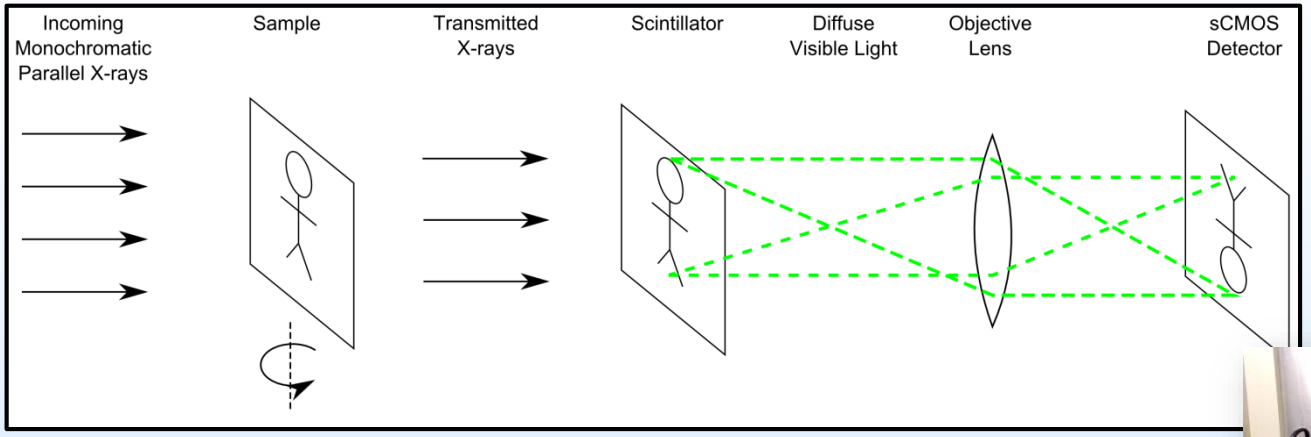
Green River Shale

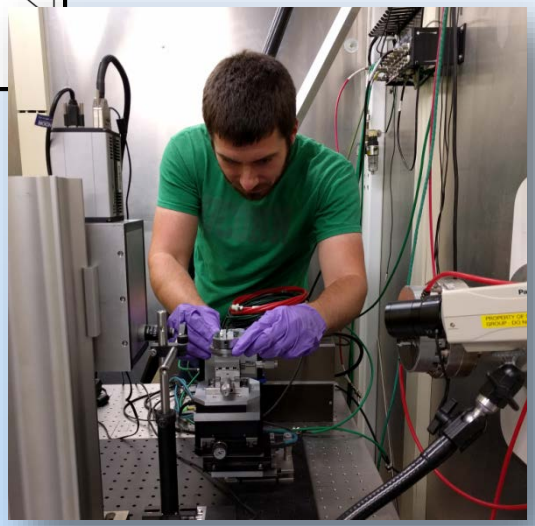
Technical Status:
Microstructure and Porosity Characterization

- Porosity
  - Synchrotron-based microCT
  - Lab-based microCT
  - FIB-SEM
- Mineralogy
  - SEM-EDS
- Surface morphology
  - SEM



Technical Status:
microCT





- Andor Zyla 5.5 with 4x and 10x Objective Lens
- Pixel size: down to 650 nm
- FOV: 1.33 x 1.33 mm or 3.33 x 3.33 mm
- Ability to use monochromatic or white light

- **Quantitatively and non-destructively measure local properties such as porosity**

Synergy Opportunities

- Goal: Understand how laser fluence can affect microstructure and be used for tailoring properties such as permeability

- Identifying locations of fractures for sealing
- Creating customized perforations for optimal and higher yield hydraulic fracturing
- SubTER pillar: Permeability Manipulation and Fluid Control

Accomplishments to Date:
Tasks and Milestones

- Task 1. Project Management
  - Project initiated (March 1, 2016)
  - Risk assessment complete — complete
- Task 2. Experimental Design
  - Literature search complete — complete
  - Detailed experimental plan established — complete
- Task 3. Initial Characterization — in progress
  - SEM training — complete
- Task 4. Laser Exposure — complete
  - Samples acquired and cored — complete
  - Laser exposure at Foro — complete
- Task 5. Post-treatment Characterization — in progress

Summary

- Progress to date
  - On schedule
  - Samples have been treated and ready for characterization

- Future Plans
  - Full characterization of samples before/after treatment
  - Understand how exposure affects morphology
  - Determine if it is feasible to weld shales

Thank you!

Laser Firing 3kW on Sample

Appendix

Organization Chart

- Andrew M. Kiss – Postdoctoral Scholar
- John R. Bargar – Senior Scientist
- Mark Hartney – Chief Technology Officer

- Danny Wolfe – SVP Engineering
- Daryl Grubb – Director Laser Processing

Gantt Chart

Task	Title	Month of project															
		2016										2017					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1	**Project Management**																
1.1	Project management	M															
1.2	Quarterly research performance reports					M			M			M					
1.3	Final technical report														M		
2	**Experimental Design**																
2.1	Literature search																
2.2	Establish a detailed experimental plan	M															
3	**Initial Characterization**																
3.1	Fracture surface chemistry																
3.2	Mineralogy																
3.3	Porosity																
4	**Laser Exposure**																
4.1	Samples exposed to laser fluence																
4.2	Returned to SLAC for characterization																
5	**Post-treatment Characterization**																
5.1	Fracture surface chemistry																
5.2	Mineralogy																
5.3	Porosity																
6	**Publish**																
6.1	Draft manuscript																
6.2	Review manuscript																
6.3	Manuscript submission																M

Bibliography

Invited Presentation

1. “Characterization of Chemical and Morphological Changes in Shales Using Synchrotron Based X-ray Imaging,” Stanford Center for Carbon Storage Annual Meeting, Stanford University, May 11, 2016.