Center for Mechanistic Control of Unconventional Formations (CMC-UF)

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This talk has 2 main sections

• The "shale revolution" has impacted the economy and the environment

• Improved chemical, physical, and mechanical understanding of nanoporous media are needed
  • multiscale, multimodal imaging of shale fabric
  • fluid phase behavior in nanoporous media
  • fracture mechanics and frictional slip on fractures

(+economics
(+carbon emissions
(+renewables adoption

(-)water
(-)recovery factor

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Switch from coal to gas

US Coal Production

- prediction using 1856-2008 data
- prediction using 1856-2018 data
- Data

Avoided CO₂ Emissions

- 50% natural gas, 50% renewables
- 50% natural gas with CCS, 50% renewables

1 wedge = 92 GtCO₂

50/50 CCS net 2.3 wedges
50/50 net 1.9 wedges

50% natural gas, 50% renewables
50% natural gas with CCS, 50% renewables
Abundant NG has enabled renewables

Typical March 31 in California

MEGAWATTS (X1000)

ENERGY USE

EXCESS RENEWABLES

2AM 4AM 6AM 8AM 10AM 12PM 2PM 4PM 6PM 8PM 10PM

NATURAL GAS IMPORTS WIND SOLAR

NUCLEAR HYDRO BIOMASS/GAS

GEOTHERMAL EXCESS RENEWABLES
"Typical" unconventional recovery factors

- gas: 25% of resource
- oil: 5% of resource

Ultimate recovery and water

<table>
<thead>
<tr>
<th>Play</th>
<th>million gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marcellus Shale, PA</td>
<td>4.4</td>
</tr>
<tr>
<td>Wattenburg Sandstone, CO</td>
<td>2.7</td>
</tr>
<tr>
<td>Barnett, Shale TX</td>
<td>2.8</td>
</tr>
<tr>
<td>Eagle Ford Shale, TX</td>
<td>4.3</td>
</tr>
<tr>
<td>Haynesville Shale, TX</td>
<td>5.7</td>
</tr>
<tr>
<td>Bakken, ND</td>
<td>1.5</td>
</tr>
<tr>
<td>Horn River Shale, BC</td>
<td>15.8</td>
</tr>
</tbody>
</table>

http://www.usgs.gov/faq/categories/10132/3824%20
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  (+)economics
  (+)carbon emissions
  (+)renewables adoption
  (-)water
  (-)recovery factor

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(-)water recovery factor
What is an Energy Frontier Research Center (EFRC)?

- Program run by US DOE Basic Energy Sciences (BES)
- Basic science with a scope and complexity beyond what is possible in standard single-investigator or small-group awards.
- Multi-investigator, multi-disciplinary, multi-site centers to enable, encourage, and accelerate transformative scientific advances for the most challenging energy-related topics.
- Research focused on one or more “grand challenges,” “transformative opportunities,” and “basic research needs” identified in major strategic planning efforts by BES and the scientific community.
Increase long-term productivity of hydraulically fractured resources while reducing environmental impacts

- Focus on interfaces, heterogeneity, disorder, and coupled physical/chemical processes at length scales from nanometers to meters.
- Integrated experimental measurements, theory development, computational tools, and scale translation activities.
Mission and Vision

• Seek fundamental mechanistic understanding of the various non-equilibrium chemical, physical, and mechanical processes occurring in shale.

• Achieve mechanistic control of nanoporous media such that hydrocarbon production increases while decreasing environmental impacts such as the amount of produced water, contaminants, and the number of wells drilled.

• Informally: Accelerate progress toward “energy dominance,” and DOE goals, through expansion of fundamental scientific knowledge.
Two Unique Geoscience Data Sets

HFTS—Hydraulic Fracture Test Site
Wolfcamp Formation

- Gas Technology Institute and DOE NETL
- 400 fracture stages in 11 wells
- Pre and post fracturing core samples
- Through-fracture core sample documents the physical properties of the fractures
- Data: core samples, core photos, logs, mineralogy, and so on

Eagle Ford—Stimulated Rock Volume

- ConocoPhillips
- Horizontal producer surrounded by 5 deviated wells
- Data acquisition program: core, image log, microseismic, DTS/DAS, and pressure data
Theme 1: Characterization

Multiscale and multi-instrument imaging to characterize and analyze nanoporous shale fabric.
Themes 2, 3, and 4: Multiscale & Multiphysics

- Transport mechanisms—Single and multiphase flow including sorption
- Reactivity at interfaces and its impact on transport
- Shale mechanics in the presence of nonaqueous and aqueous fluids

Theme 1: Characterization

Multiscale and multi-instrument imaging to characterize and analyze nanoporous shale fabric.
**Theme 5: Scale Translation**

**Across scale interaction and coupling honored**

**Themes 2, 3, and 4: Multiscale & Multiphysics**

- Transport Mechanisms—Single and multiphase flow including sorption
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**Theme 1: Characterization**

- Multiscale and multi-instrument imaging to characterize and analyze nanoporous shale fabric.
Theme 1: Multi-scale, -instrument, and -physics Imaging

Example – Shale, CO₂ Storage Capacity ($\xi$)

**Top down imaging:** whole core images (2.5 cm diameter) with CO₂, Kr, or Xe in pore space and adsorbed
- transient, • different gas types, • including stress

CT voxel: 250 x 250 x 1000 μm

Segmented TXM voxel: 30 x 30 x 30 nm


P – Pyrite; OM – Organic Matter; Matrix – mixture of clay and carbonate
Theme 3: Reactive Transport (RTM)

- Microfluidics cell that mimics topological fracture hierarchy of shale.
- Conduct a series of flow-through studies
- Build from simple transport to increasingly complex reaction networks.
- Constrain the principle factors governing RTM.

Ling, Druhan, Battiato
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ACKNOWLEDGEMENTS

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Theme 2: Transport in nanopores

What is Capillary Condensation?

Why do we care?
- Underestimate reserves 3 to 6 times (Chen et al. 2013)
- 5.5 times reduction of mass flow rate (Bui et al. 2016)
- 50% reduction of bubble point (Barsotti et al. 2018)

Open question disordered porous media:
Topology/morphology $\leftrightarrow$ Capillary Condensation

Minkowski functionals link geometry and thermodynamics

Study Capillary Condensation as function of:
- Volume
- Surface area
- Curvature
- Gaussian curvature

Boelens and Tchelepi
Theme 4: Mechanics

Does Fracture Permeability and Compliance Change with CO$_2$-Rich Frac Fluids?

Initial Experiments with 4 Samples from Eagle Ford

Kohli, Zoback, and others
Theme 5: Scale translation

- bottom-up physics-based approaches
- rigorous upscaling
- effective medium representations result in diagnosis criteria that identify suitable models at which continuum-scale quantities and parameters are well defined

- top-down deployment balances accuracy and computational burden

Battiato and Wang
CMC-UF Priority Research Directions
Follow from DOE-BES Basic Research Needs

• Predict static and dynamic properties of multicomponent fluids;
• Achieve mechanistic control of interfaces and transport in complex and extreme environments;
• Characterize and control matter away—especially very far away—from equilibrium;
• Advance science to harness the subsurface for a transformational impact on water;
• Empower a highly trained and diverse scientific workforce whose members possess depth in one or two areas and are able to collaborate across a breadth of scientific and technical fields.