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CENTER FOR MECHANISTIC CONTROL OF WATER-HYDROCARBON-ROCK INTERACTIONS IN UNCONVENTIONAL AND TIGHT OIL FORMATIONS

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

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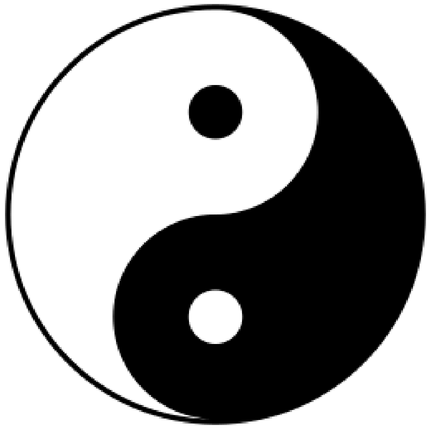
Stanford UW USC SLAC ILLINOIS

This talk has 2 main sections

- The ”shale revolution” has impacted the economy and the environment

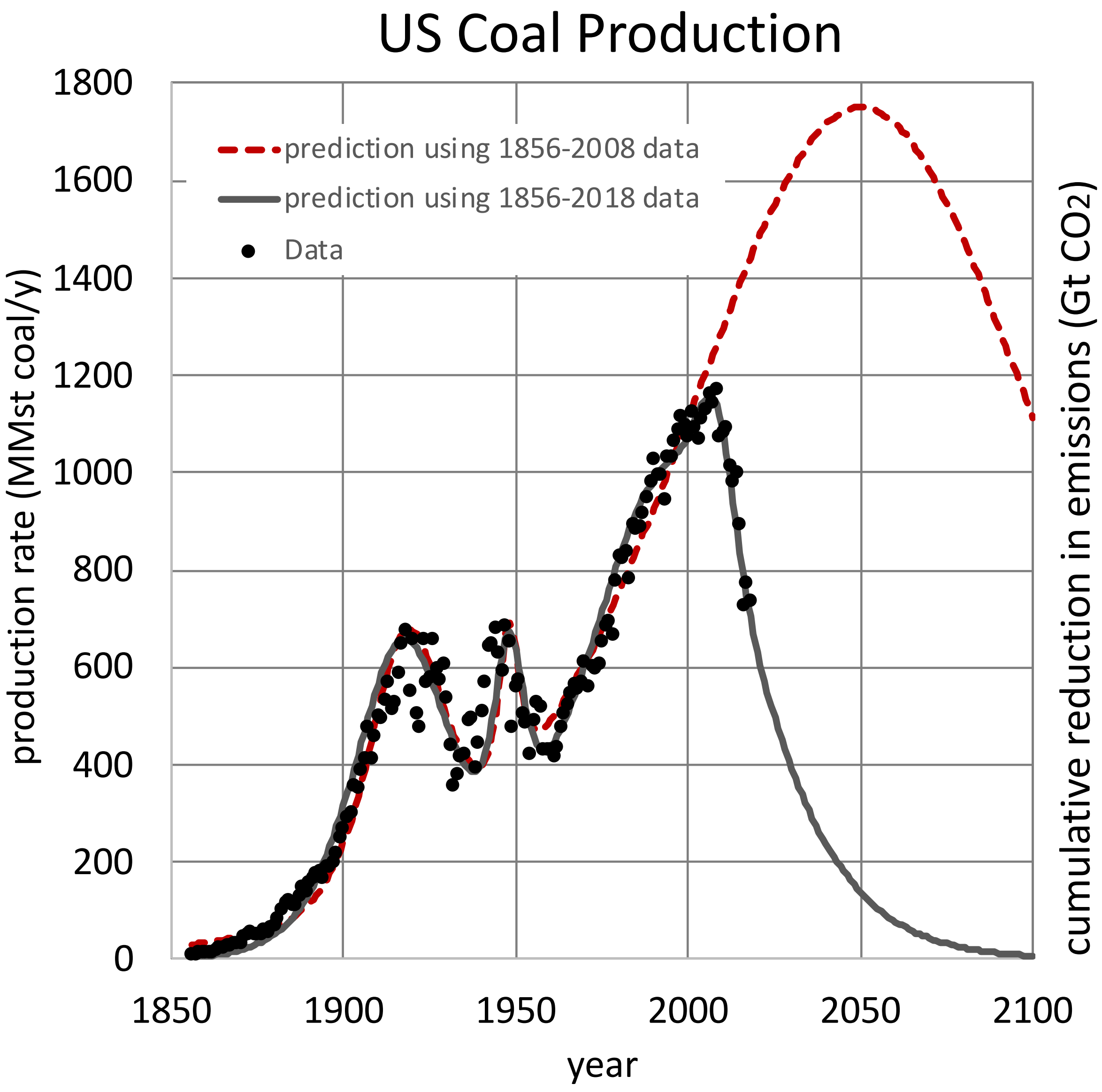
(+)economics
(+)carbon emissions
(+)renewables adoption

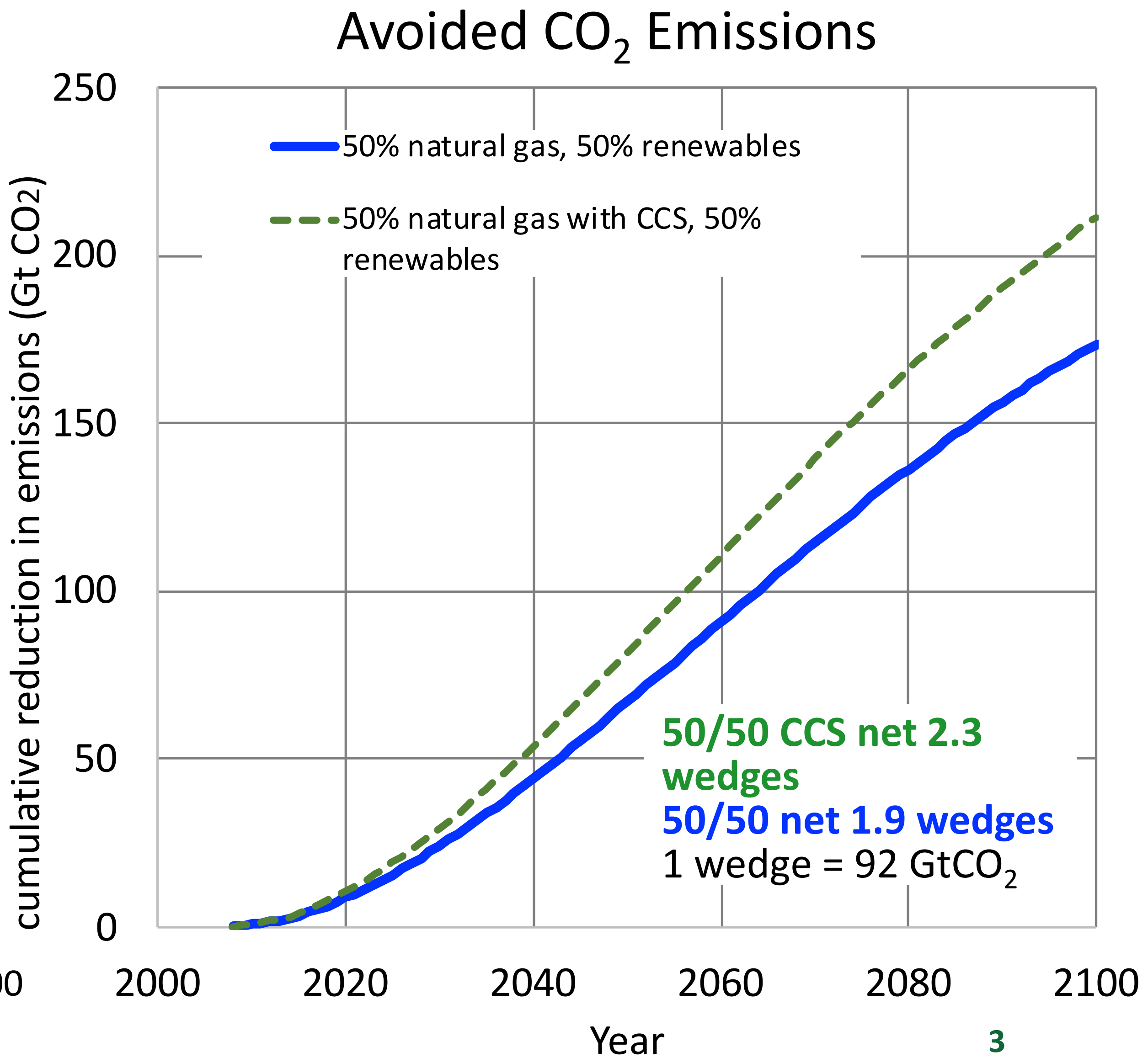


(-)water
(-)recovery factor

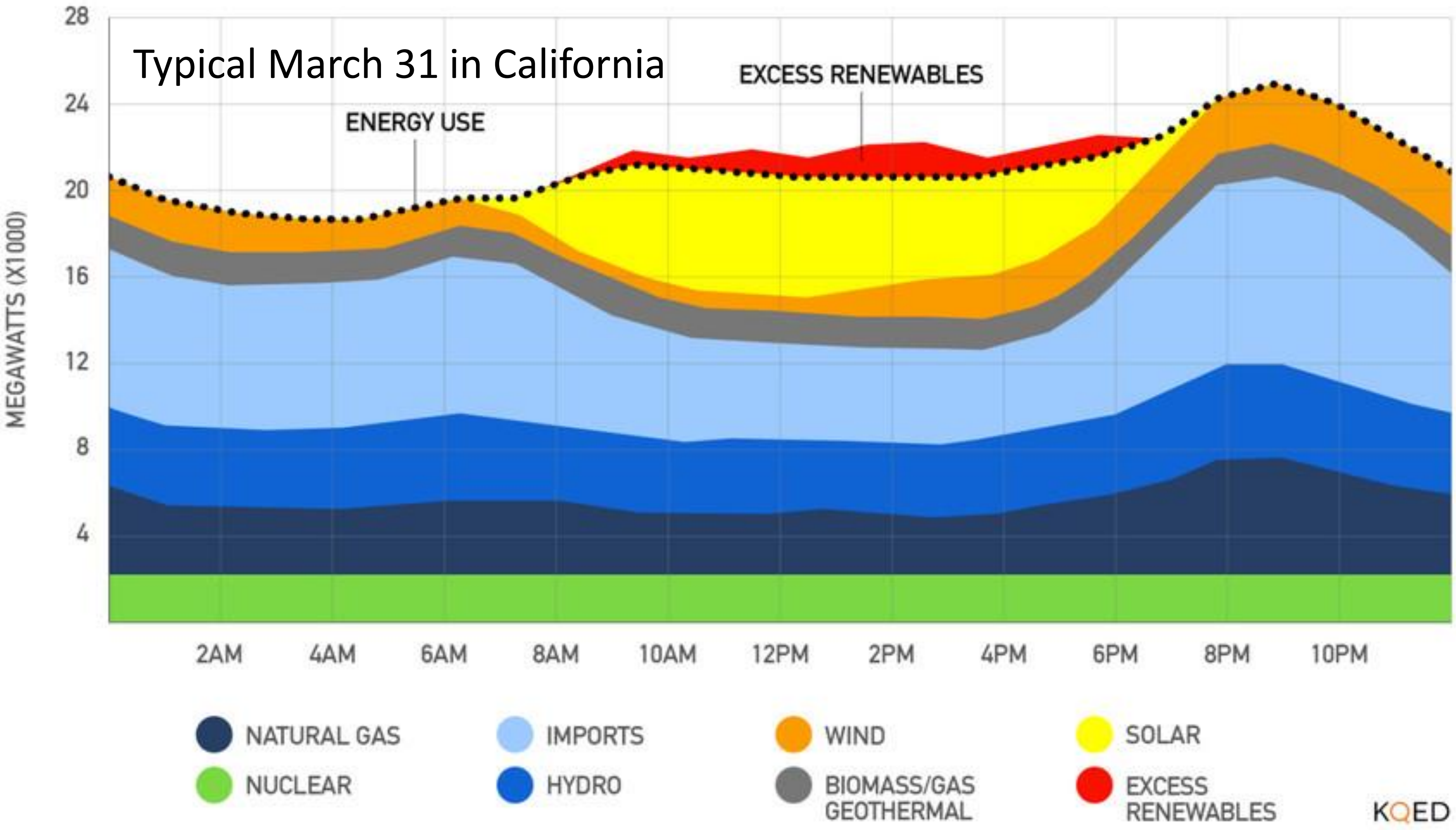
- Improved chemical, physical, and mechanical understanding of nanoporous media are needed
  - multiscale, multimodal imaging of shale fabric
  - fluid phase behavior in nanoporous media
  - fracture mechanics and frictional slip on fractures

Switch from coal to gas

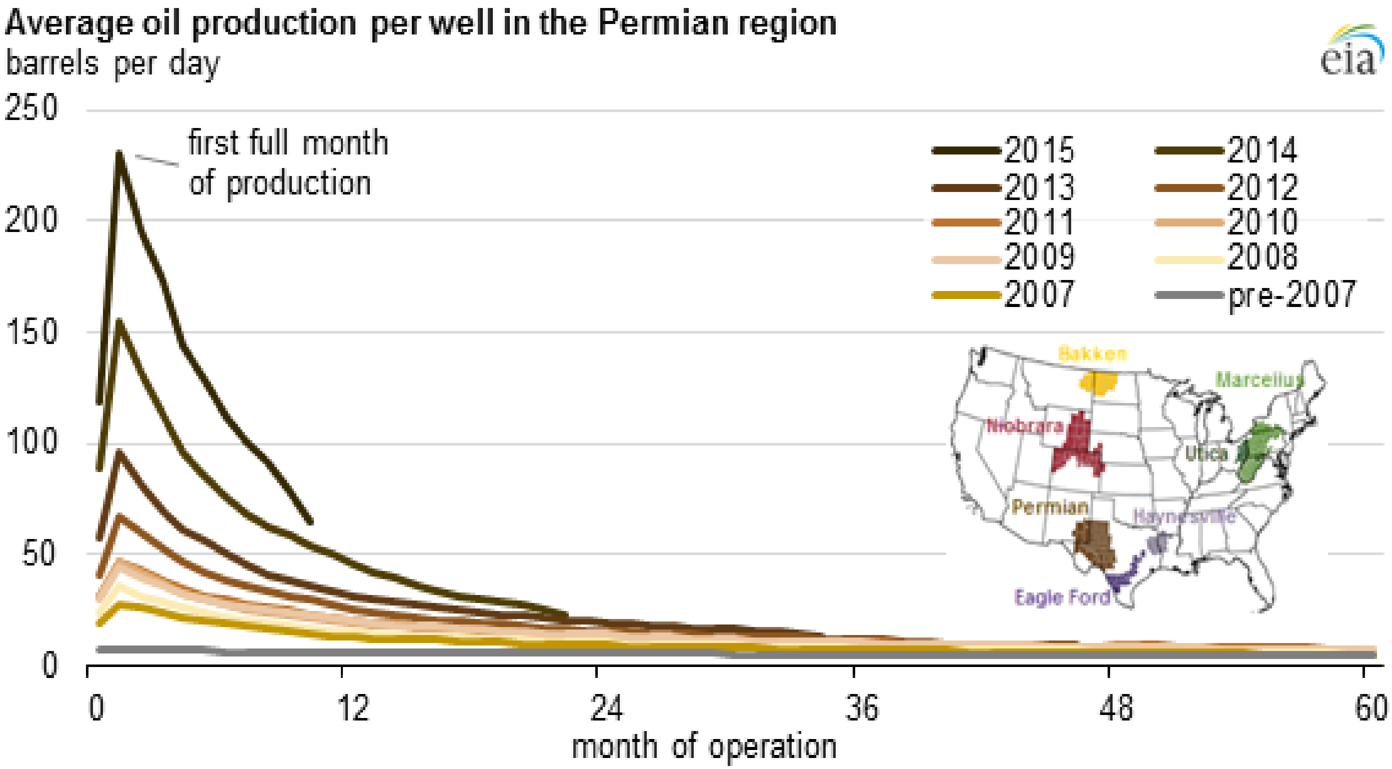




Abundant NG has enabled renewables



Ultimate recovery and water



"Typical" unconventional recovery factors

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

Play	million gallons
Marcellus Shale, PA	4.4
Wattenburg Sandstone, CO	2.7
Barnett, Shale TX	2.8
Eagle Ford Shale, TX	4.3
Haynesville Shale,TX	5.7
Bakken, ND	1.5
Horn River Shale,BC	15.8

http://www.usgs.gov/faq/categories/10132/3824%20

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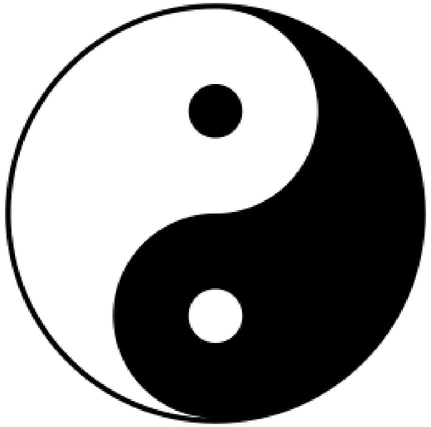

(-)water
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  - fluid phase behavior in nanoporous media
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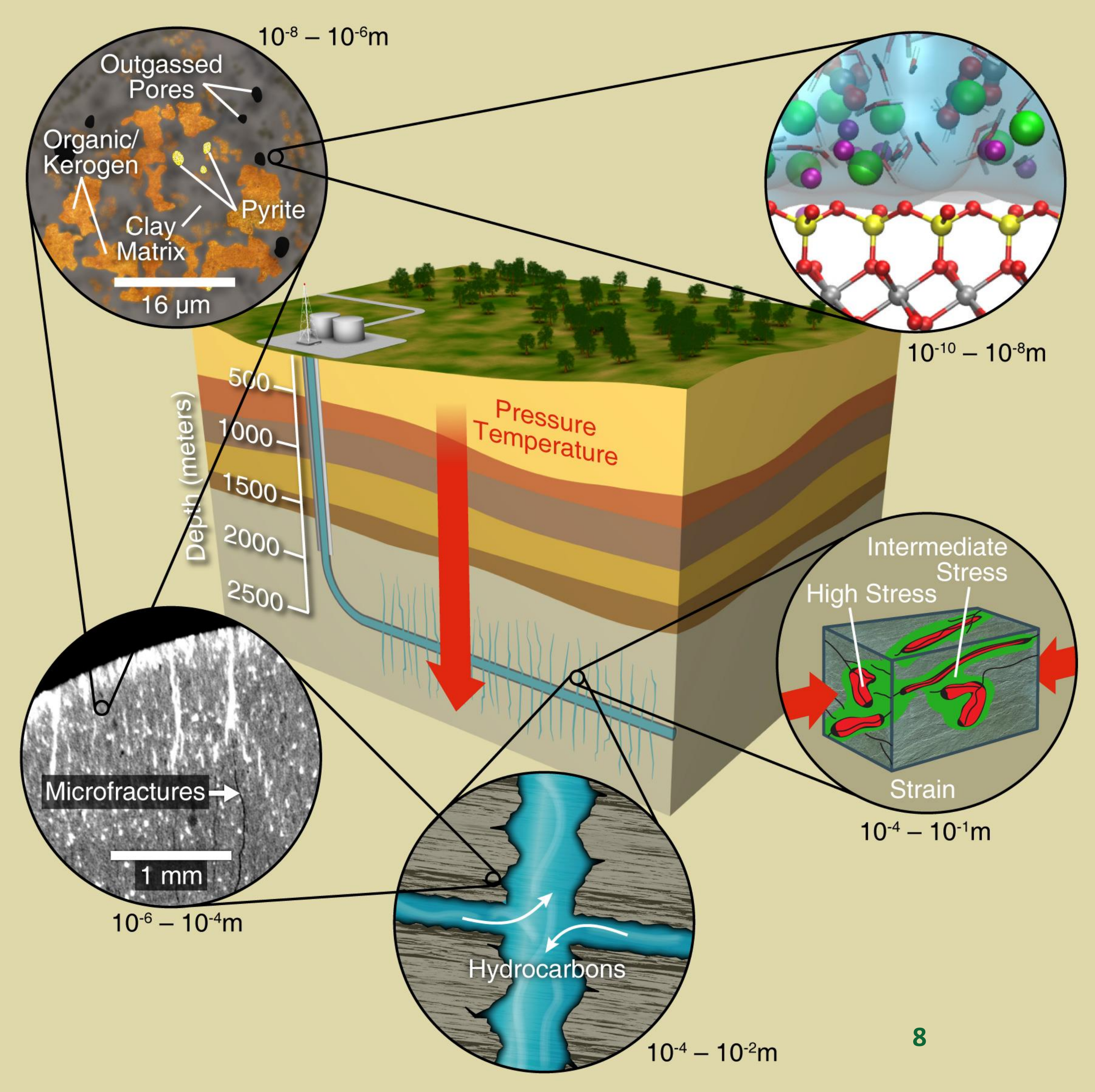
What is an Energy Frontier Research Center (EFRC)?

- 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.

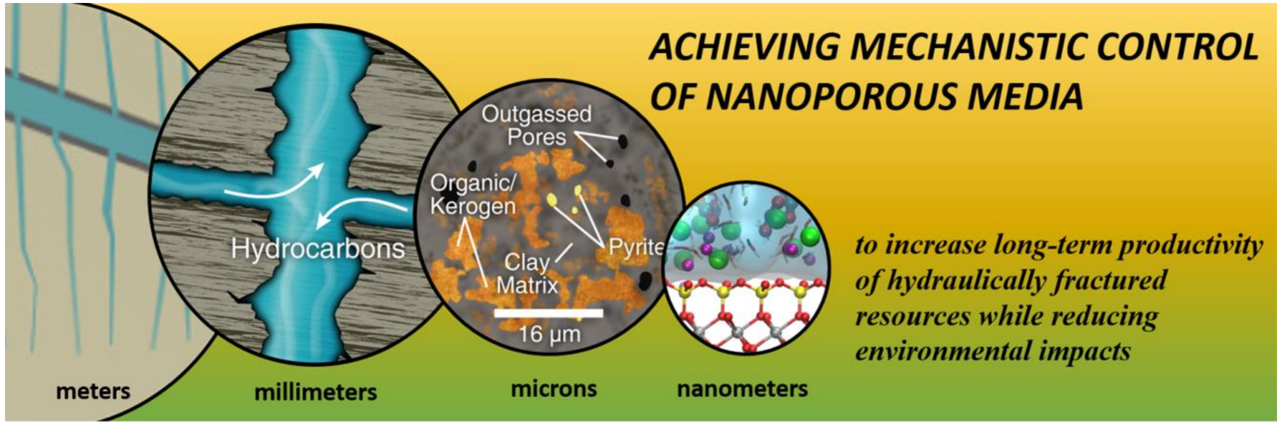
Increase long-term productivity of hydraulically fractured resources while reducing environmental impacts

- 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

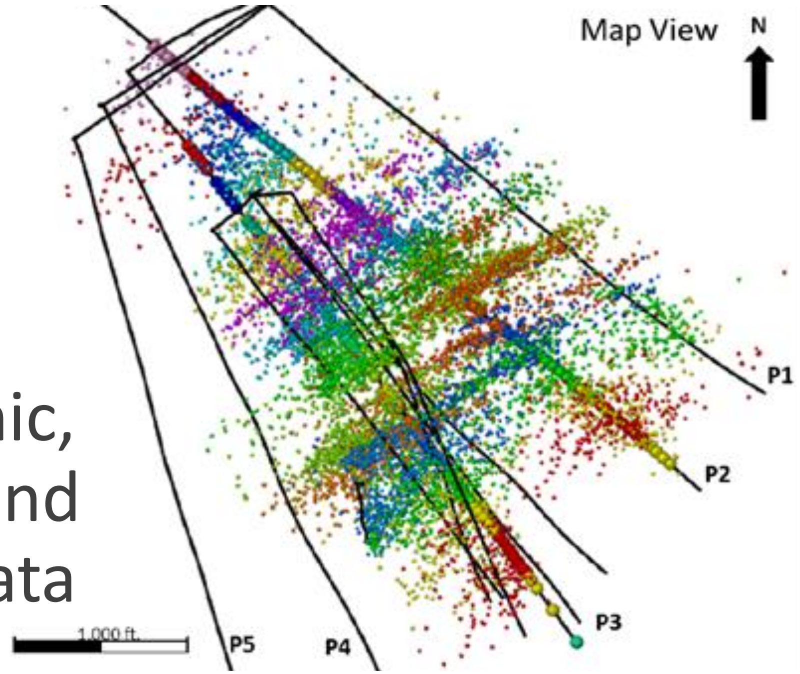
HFTS—Hydraulic Fracture Test Site

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



5 Interlocking Themes

Theme 1: Characterization

Multiscale and multi-instrument imaging to characterize and analyze nanoporous shale fabric.

5 Interlocking Themes

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.

5 Interlocking Themes

Theme 5: Scale Translation

Across scale interaction and coupling honored

Physics based bottom-up model development and top-down deployment

Themes 2, 3, and 4: Multiscale & Multiphysics

Transport Mechanisms—Single and multiphase flow including sorption

Reactivity at interfaces and its impact on transport

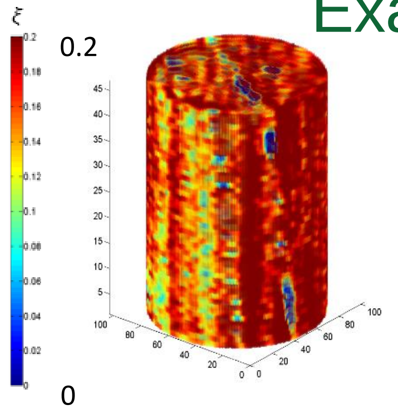
Shale mechanics in the presence of nonaqueous and aqueous fluids

Theme 1: Characterization

Multiscale and multi-instrument imaging to characterize and analyze nanoporous shale fabric.

Theme 1: Multi-scale, -instrument, and -physics Imaging

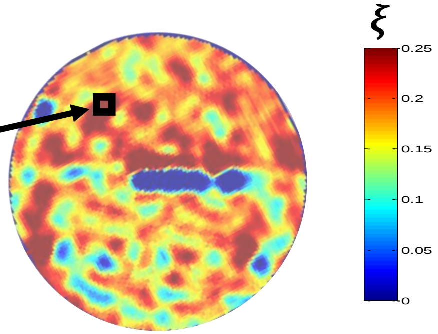
Example – Shale, CO_2 Storage Capacity (ξ)



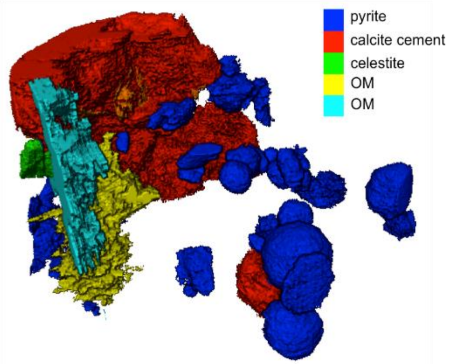
Top down imaging: whole core images (2.5 cm diameter) with CO_2, Kr, or Xe in pore space and adsorbed

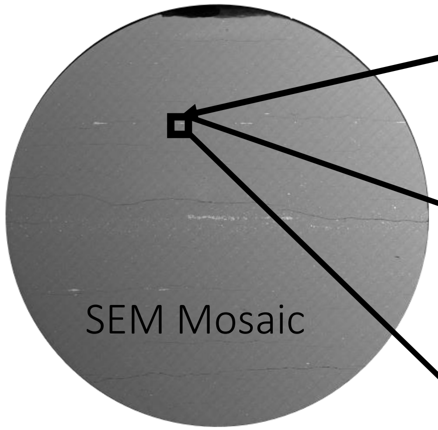
• transient, • different gas types, • including stress

CT voxel: 250 x 250 x 1000 μm



Segmented TXM voxel: 30 x 30 x 30 nm

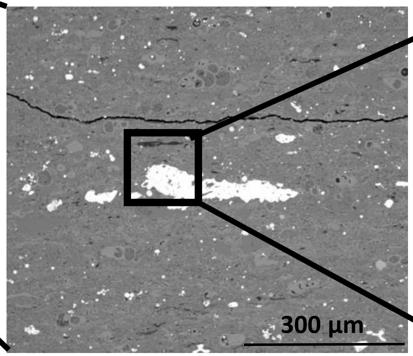




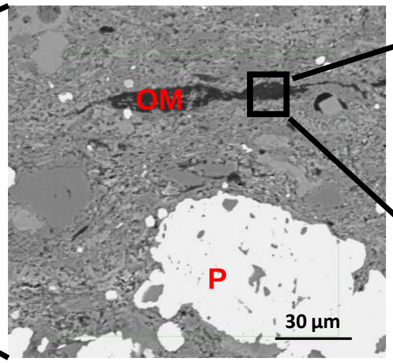
1 inch diameter

Pixel Size: 1.45 µm

SEM Multiscale Images

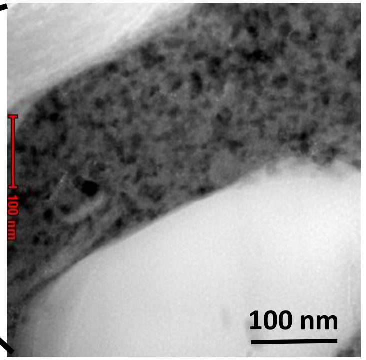


Pixel Size: 366 nm



Pixel Size: 74 nm

TEM Multiscale Images



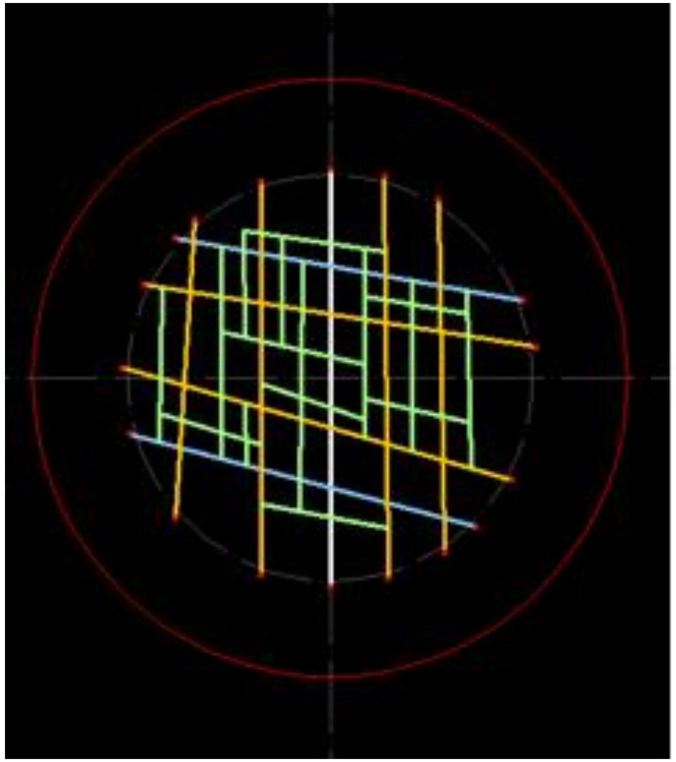
Pixel Size: 2 nm

Aljamaan, H. C. M. Ross, and A. R. Kovscek, *Society of Petroleum Engineers Journal*, 22(6), 1760-1777 (2017).
Vega, B., C. M. Ross, and A.R. Kovscek, *Society of Petroleum Engineers Journal*, 20(4) 810-823 (2015
Foute, L., Nanoimaging of Shale Using Electron Microscopy Techniques, Stanford University (2019).

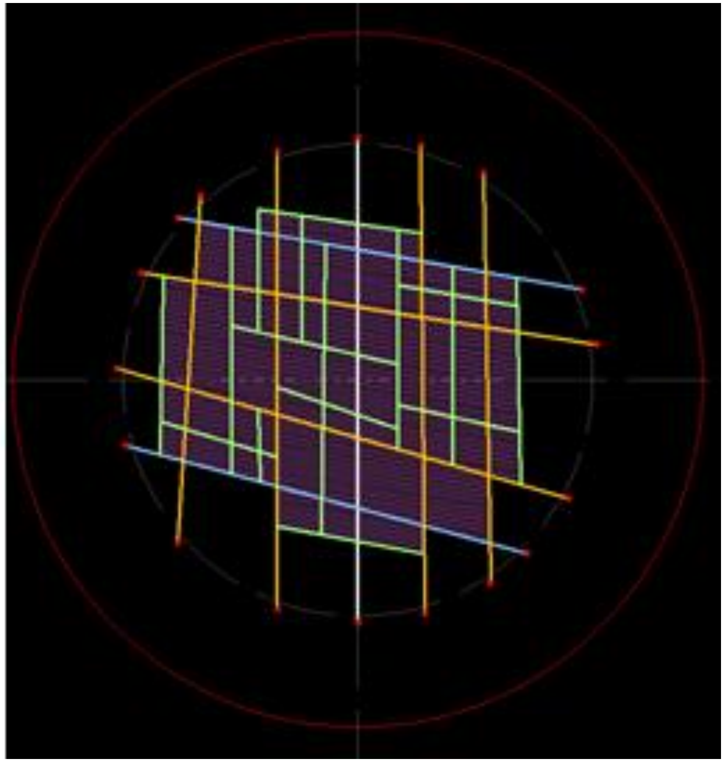
P – Pyrite; OM – Organic Matter; Matrix – mixture of clay and carbonate

Theme 3: Reactive Transport (RTM)

Primary Fractures



Fractures + microfractures

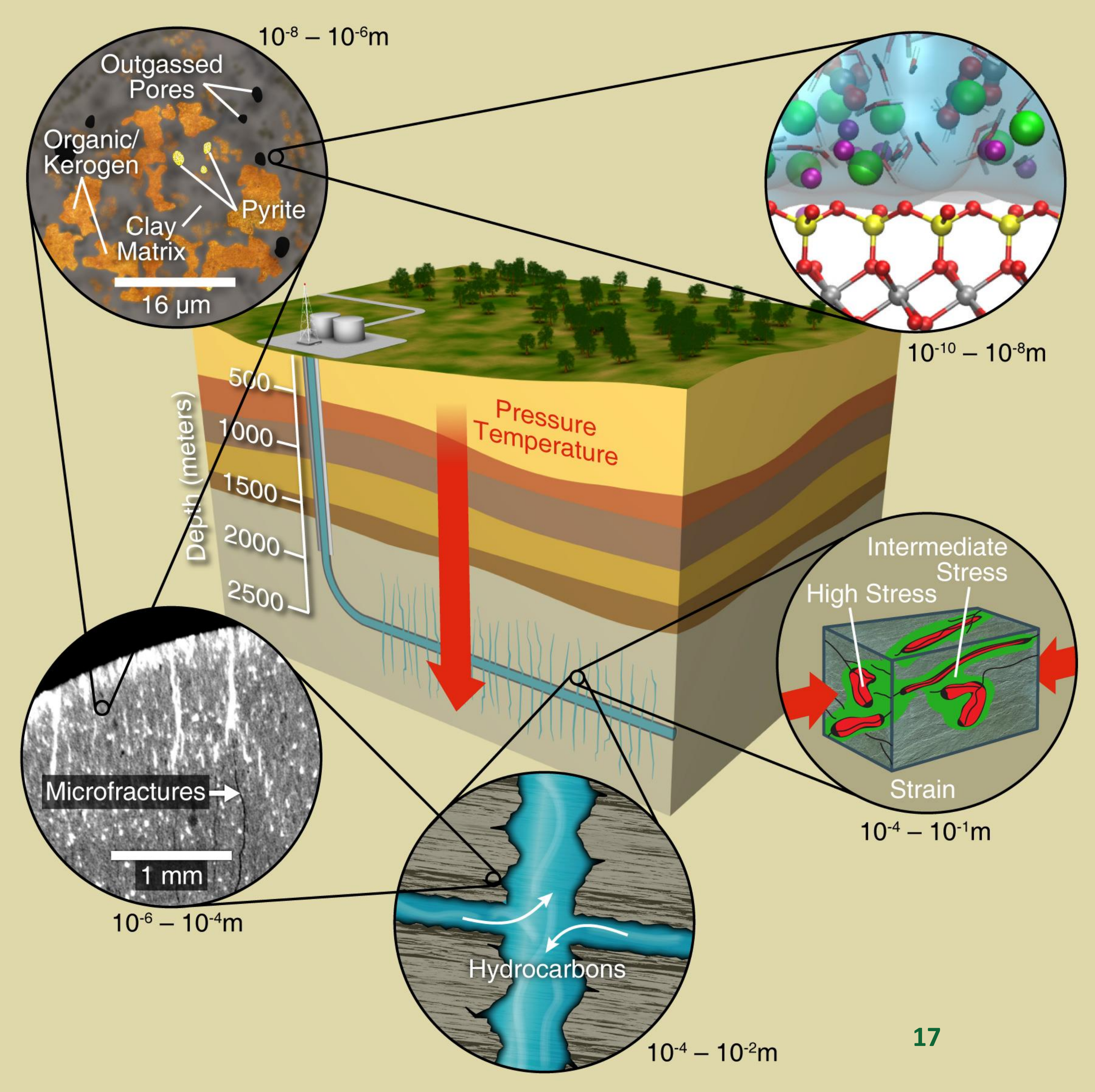


- Microfluidics cell that mimics topological fracture hierarchy of shale.
- Conduct a series of flow-through studies
- Build from simple transport to increasingly complex reaction networks.
- Constrain the principle factors governing RTM.

Ling, Druhan, Battiato

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.



ACKNOWLEDGEMENTS

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This work was supported as part of the Center for Mechanistic Control of Water-Hydrocarbon-Rock Interactions in Unconventional and Tight Oil Formations (CMC-UF), an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science under *DOE (BES) Award DE-SC0019165.*

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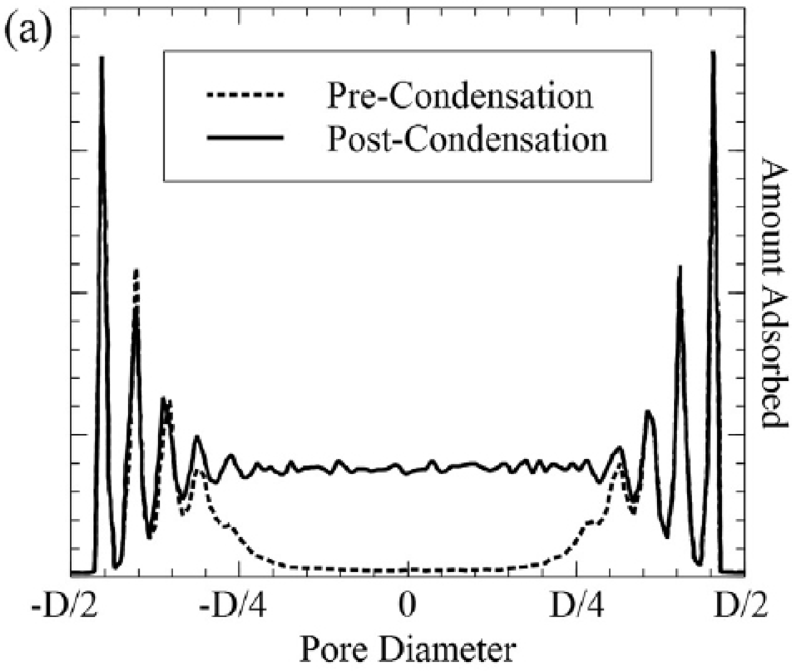
Theme 2: Transport in nanopores

What is Capillary Condensation?



$P_{cond} < P_{sat}$

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:

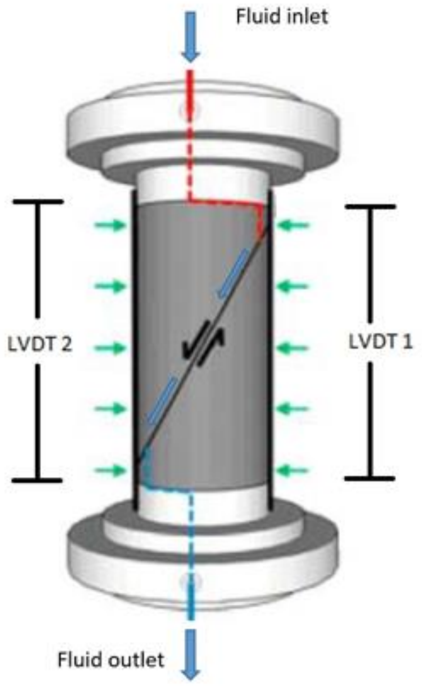
Topology/morphology ⟷ *Capillary Condensation*

<u>Minkowski functionals</u> link geometry and thermodynamics

Study Capillary Condensation as function of:

- Volume
- Surface area
- Curvature
- Gaussian curvature

Theme 4: Mechanics



Does Fracture Permeability and Compliance Change with CO_2-Rich Frac Fluids ?

Initial Experiments with 4 Samples from Eagle Ford

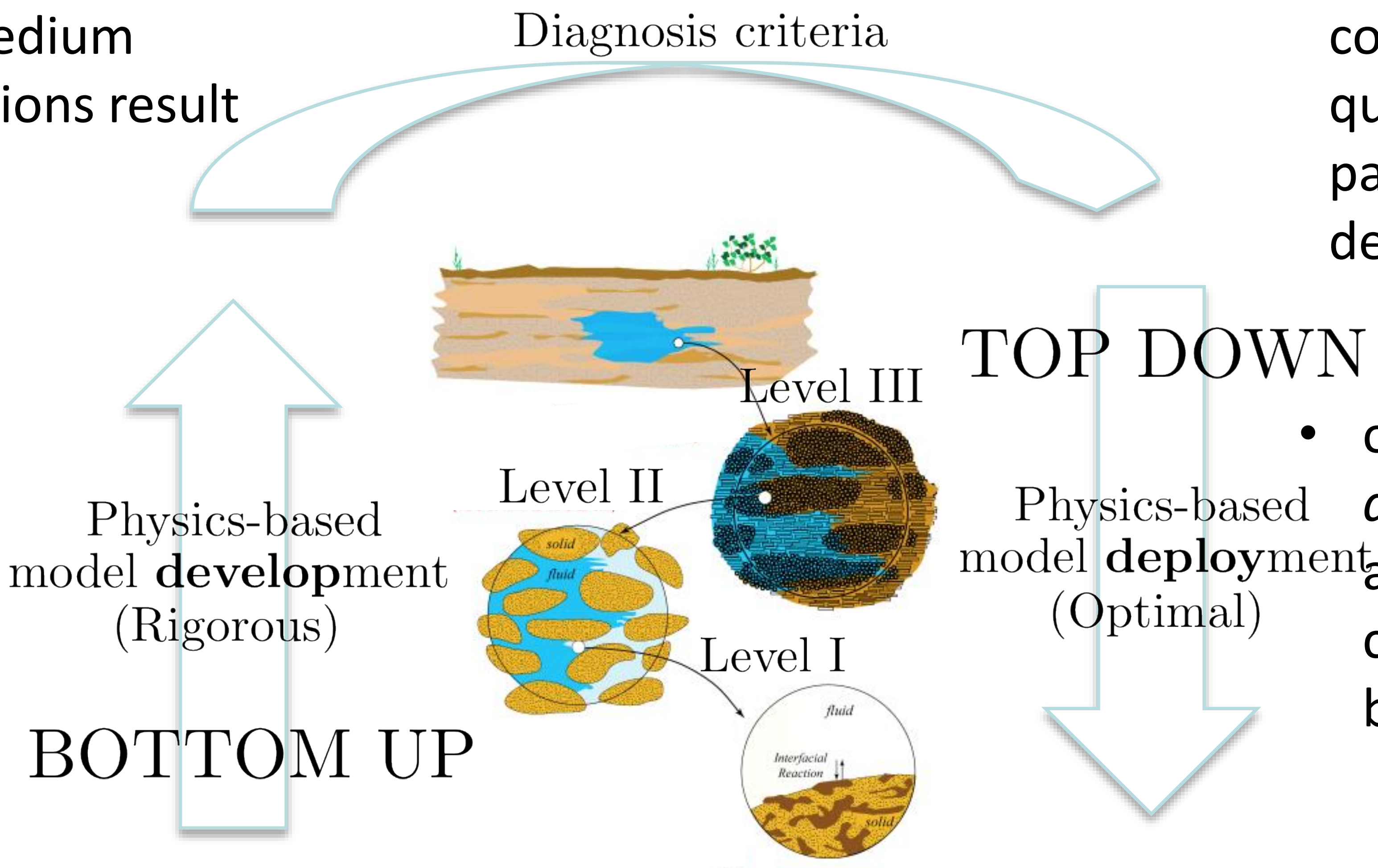
TECTOSILICATES			CARBONATES			PHYLLOSILICATES (CLAY GROUP MINERALS)				ADDITIONAL MINERALS				ORGANICS	TOTAL				
Quartz	K-spar	Plag.	Calcite^	Dolomite‡	Siderite	Chlorite	Kaolinite	Illite/Mica	Mx I/S	Pyrite	Marcasite	Apatite	Barite	TOC	TECTOSILICATES	CARBONATES	PHYLLOSILICATES	ADDITIONAL	ORGANICS
11.5	0.6	4.8	60.6	0.6	0.0	0.5	0.0	9.0	6.4	1.6	1.6	Tr	0.0	2.8	16.9	61.2	15.9	3.2	2.8
11.0	0.6	1.5	48.1	Tr	0.0	1.3	11.9	10.8	5.7	2.1	1.9	Tr	0.0	5.1	13.1	48.1	29.7	4.0	5.1
8.8	0.7	4.7	62.0	0.5	0.0	0.6	0.0	10.3	7.6	1.5	1.0	Tr	0.0	2.3	14.2	62.5	18.5	2.5	2.3
11.0	4.0			71.0			11.0			0.7					15.0	71.0	11.0		

Kohli, Zoback, and others

Theme 5: Scale translation

- bottom-up physics-based approaches
- rigorous upscaling
- effective medium representations result

- diagnosis criteria identify suitable models at which continuum-scale quantities and parameters are well defined



- optimal top-down *deploy*ment 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.