NATIONAL ENERGY TECHNOLOGY LABORATORY

Status Update
EPAct 2005 Title IX, Subtitle J Section 999 A(b)(4)
NETL's Complementary Research Program
September 2009

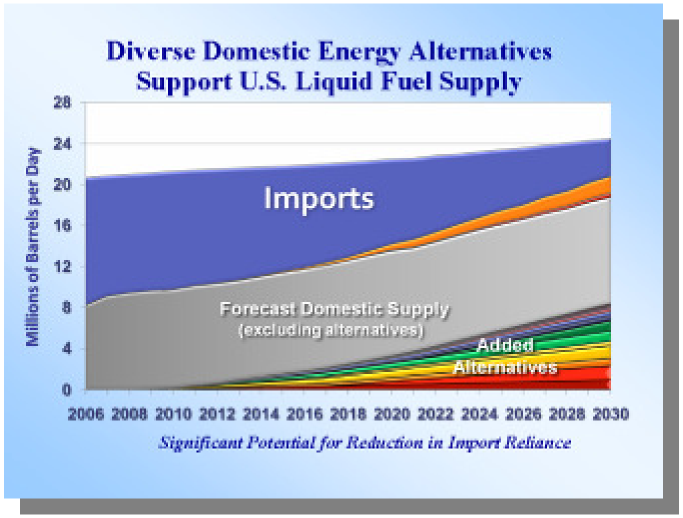
George Guthrie, Focus Area Leader

Geological & Environmental Systems

Office of Research and Development

Complementary Program consists of research conducted by NETL's ORD and OSAP.

Office of Research & Development	*Office of Systems, Analysis, & Planning*	**Extramural Research and Collaboration**



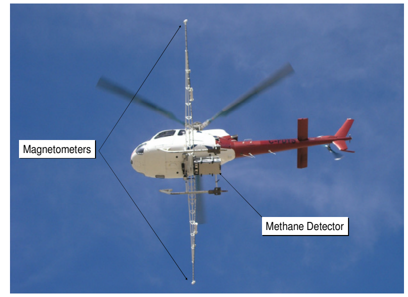
- **Annual Merit Review** (this year held on 15–16 July 2009)
  - External panel review of scientific and technical quality of projects
- **Annual Technical Committee Review** (this year held on 6 August 2009)
  - Annually assesses complementary and non-duplicative nature
- **Institute for Advanced Energy Solutions (IAES)**
  - NETL institute that engages university community for joint R&D

Geological/Environmental Research Areas

Science/engineering research of natural systems to enable the clean production & utilization of fossil energy

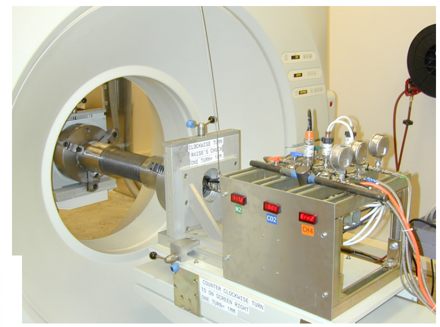
CO_2 Storage

- Capacity, injectivity, long-term fate
- Seal integrity (cement durability)
- Potential impacts (fluid-rock interactions)
- Monitoring and assessment (including GIS, risk assessment)



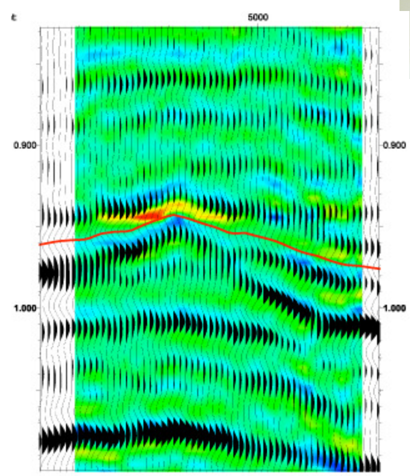
Oil, gas, unconventional fossil fuels

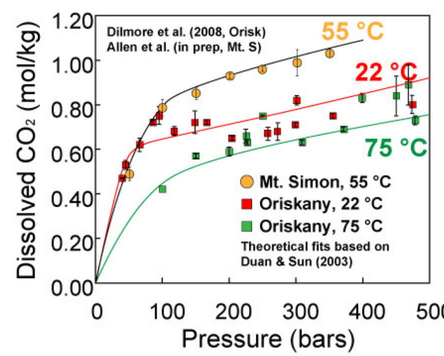
- ➢ Extreme drilling (deep & ultradeep)
- ➢ Environmental impacts
- ➢ Unconventional oil & gas (including EOR)
- ➢ Resource assessment (geospatial data)
- Methane hydrates



Main Competencies

- Drilling under extreme conditions
- Multiscale/multiphase fluid flow (including fractured media)
- Geomaterials science
- Field-based monitoring
- Geospatial data management/assessment

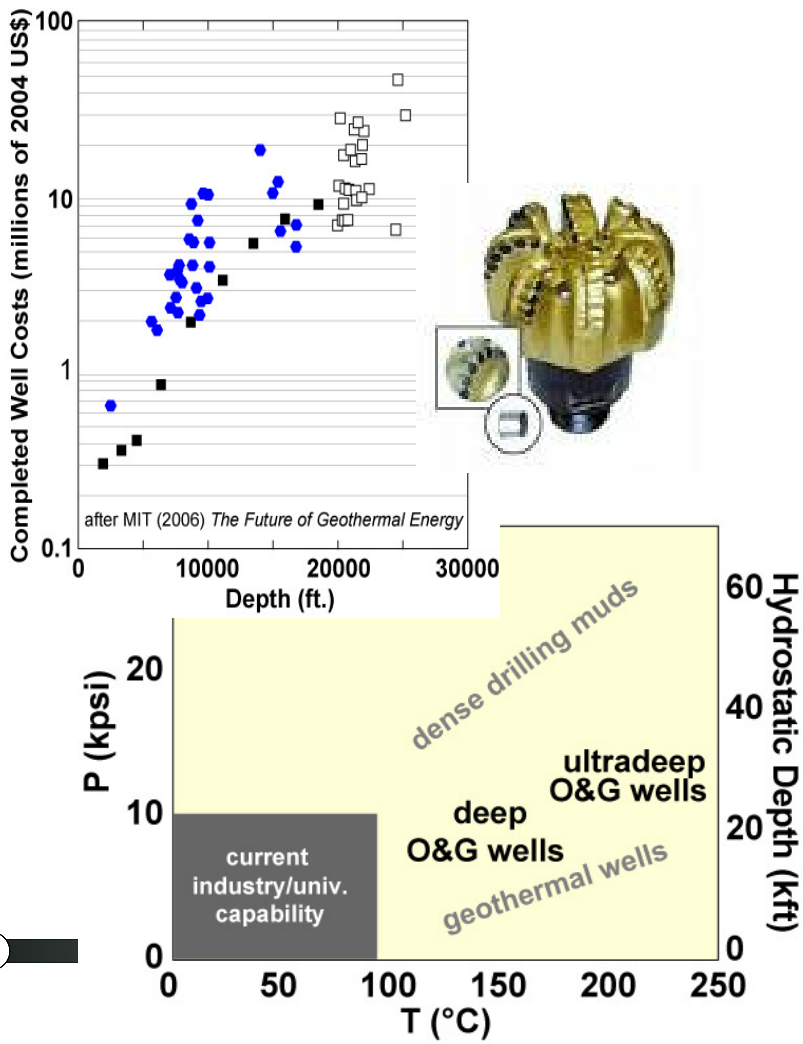




		Ultra-Deepwater	Unconventional Gas: CBM	Unconventional Gas: Tight Gas Sands	Unconventional Gas: Gas Shales	Unconventional Oil (oil shale, oil sands, heavy oil)	Mature Fields (operated by small producers)
Resource Development	Water Mgmt.	NA	1 project (2007)				
					2 Projects (2008)		
	Reduce Costs	15 Projects (2007) 9 Projects (2008)					2 projects (2007) 1 project (2008)
	Increase Recovery		5 projects (2007), 1 project 2008			Microwave heating Fractured media models Oil shale catalysts	CO2 EOR
			2 projects (2007)	6 projects 2007 2 project (2008)	5 projects 2007 3 project (2008)		4 projects (2007) 5 projects (2008)
	Resource Character.	Subsalt Seismic Modeling (2007)			Marcellus Resource Assessment		NA
HPHT Resources	Drilling	Extreme Drilling Laboratory	NA	NA	NA	NA	NA
		HPHT Materials					
		Composite Risers (2007) Managed Pressure Drilling (2008)					
	Modeling	EOS for HPHT					
Environmental Impact Assessment and Mitigation	Surface	NA	Ecological Impact of Oil and Gas Activities (EIOG)			Environmental Impacts of Unconventional Fossil Fuel Development (Oil Shale)	EIOG
			Environmentally Friendly Drilling (2008)				Low Impact Roads (2007)
	Air		Monitoring/Modeling Air Emissions from Oil and Gas E&P Activities				
	Water		Produced Water Management				
Technology Transfer		Knowledge Management Database (KMD) and RPSEA 2.5% Tech. Transfer				KMD/RPSEA Oil shale archive	KMD/RPSEA

Drilling under Extreme Conditions

Goal: To improve the economics of drilling deep and ultra-deep wells by increasing the rate of penetration and by developing better-performing materials for extreme drilling environments



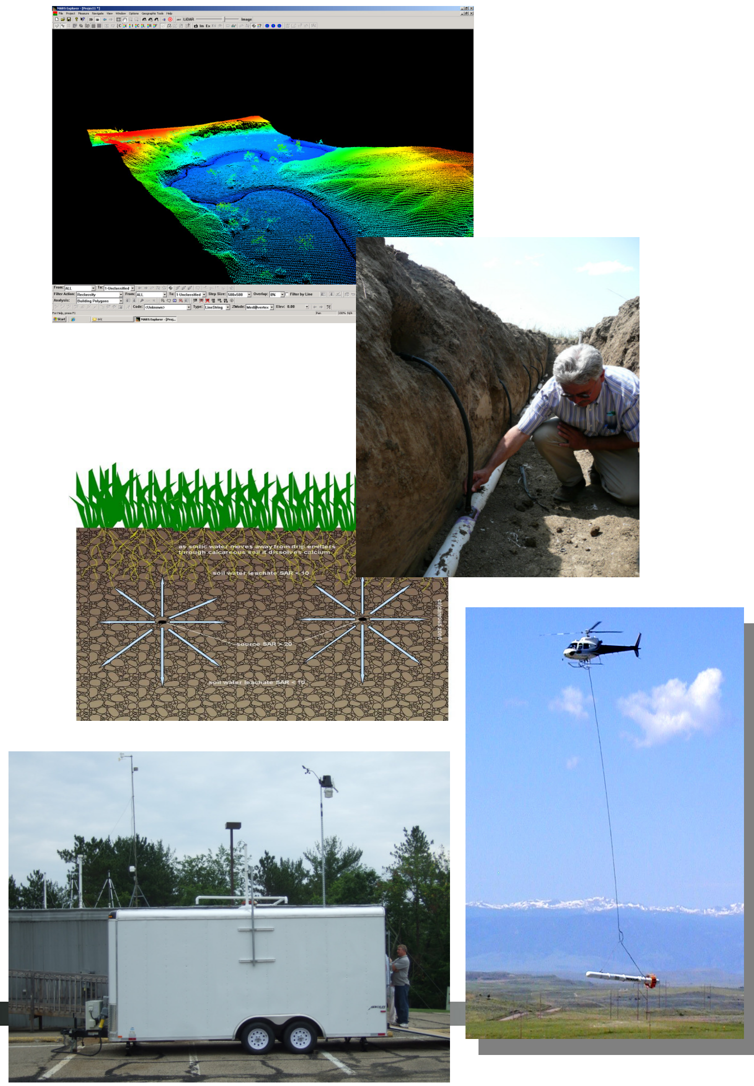
Four Elements to Research Focus

- **Experimental investigation of drilling dynamics** ★
  - **Ultra-deep Drilling Simulator (UDS) and the Extreme Drilling Laboratory**
- **Development of predictive models for drilling dynamics**
- **Development of novel nanoparticle-based fluids for improved drilling** ★
- **Improvement of materials behavior/performance in extreme environments**

★ More detail to follow

Environmental Impacts of Oil/Gas

Goal: To develop an improved, science-based understanding that leads to solutions for potential environmental challenges to oil/gas production



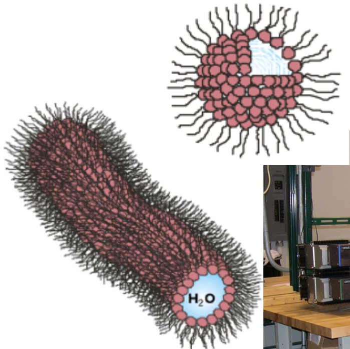
Major Elements to Research Focus

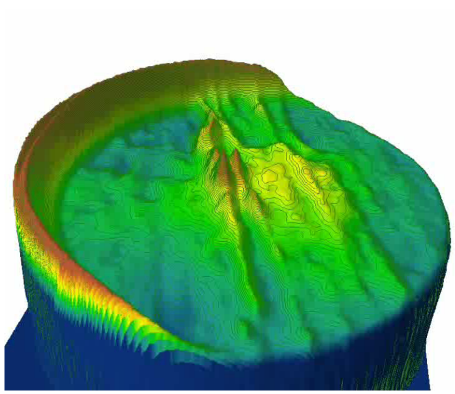
- **Evaluation of strategies for effective and environmentally sound disposition of produced waters**
  - **Produced water database (PWMIS)**
  - **Evaluation of potential options (subsurface drip irrigation; ephemeral streams)** ★
  - **Quantitative models via a portfolio of monitoring options (airborne, UAV, hyperspectral, electromagnetic, LIDAR, etc.)**
- **More accurate assessment of air-quality impacts by detailed measurement and improved computational representations**
- **(Fundamental inorganic and organic geochemistry of reservoir fluids—including natural background vs. production)**

★ More detail to follow

Unconventional Oil & Enhanced Oil Recovery

Goal: To enable broader utilization of domestic fossil resources through improved efficiency and lowered environmental impact





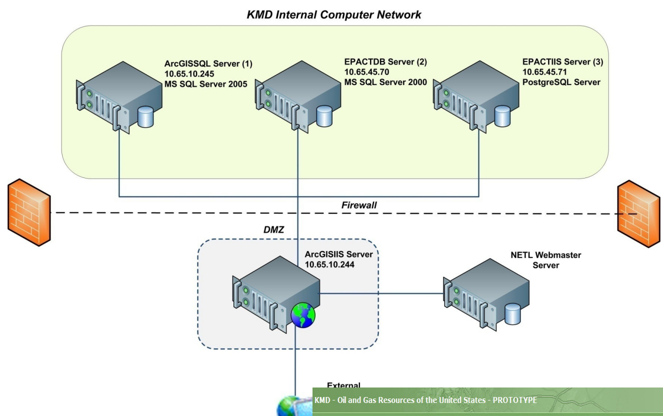
Elements to Research Focus

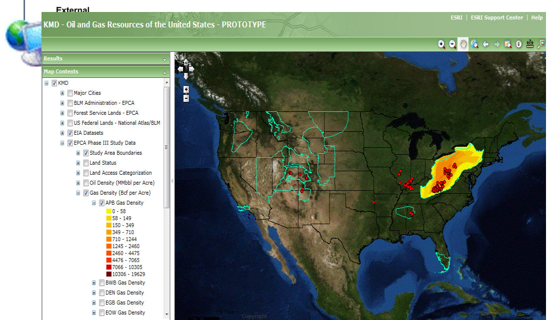
- **CO_2-enhanced oil recovery: Improved flow control by increasing CO_2 viscosity (tailored surfactants)** ★
- In-situ production of oil shale: Improved heating of kerogen by tuned microwave and CO_2
- **Oil production in fractured media: Improve accuracy/reliability of predicting primary–tertiary oil recovery in shale**
- **Catalog experience/knowledge from oil-shale and tar-sand activities**
- **(EOS for CO_2-brine-hydrocarbon at elevated PT)** ★

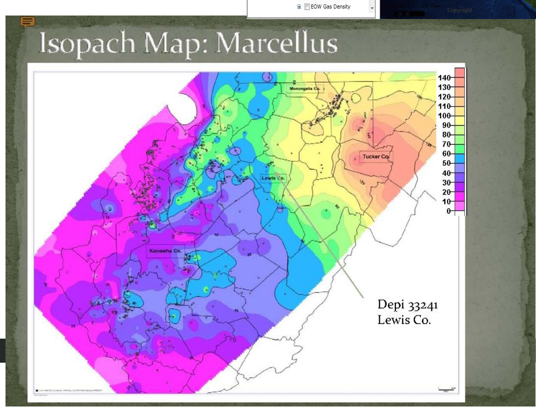
★ More detail to follow

Resource Assessment

Goal: To enable better assessment of fossil resources by collection, management, and integration of high-resolution geospatial data







Elements to Research Focus

- **Knowledge management database development**
  - **Repository for R&D results related to the Section 999 R&D program**
  - **Searchable database that also includes historical oil/gas research from NETL**
  - **ArcGIS to enable data visualization**
  - **Beta version anticipated Aug/Sept 2009**
- **Marcellus shale database: high resolution data for improved assessment**
  - **Quantitative assessment of commercial gas in place via laboratory/well-logs correlations for improved models**

Drilling under Extreme Conditions

Goal

- To elucidate drilling dynamics under high PT (up to 250 ^{o}C, 30 k psi)

Challenges

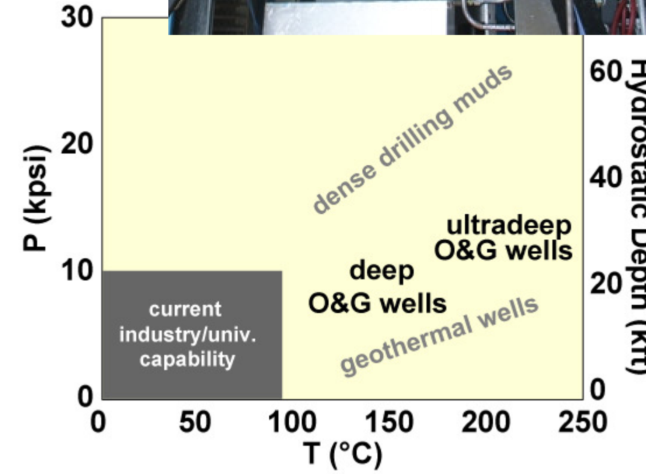
- Drilling costs increase exponentially with depth
- Observation of drilling dynamics limited (experimentally challenging)

Project Objectives

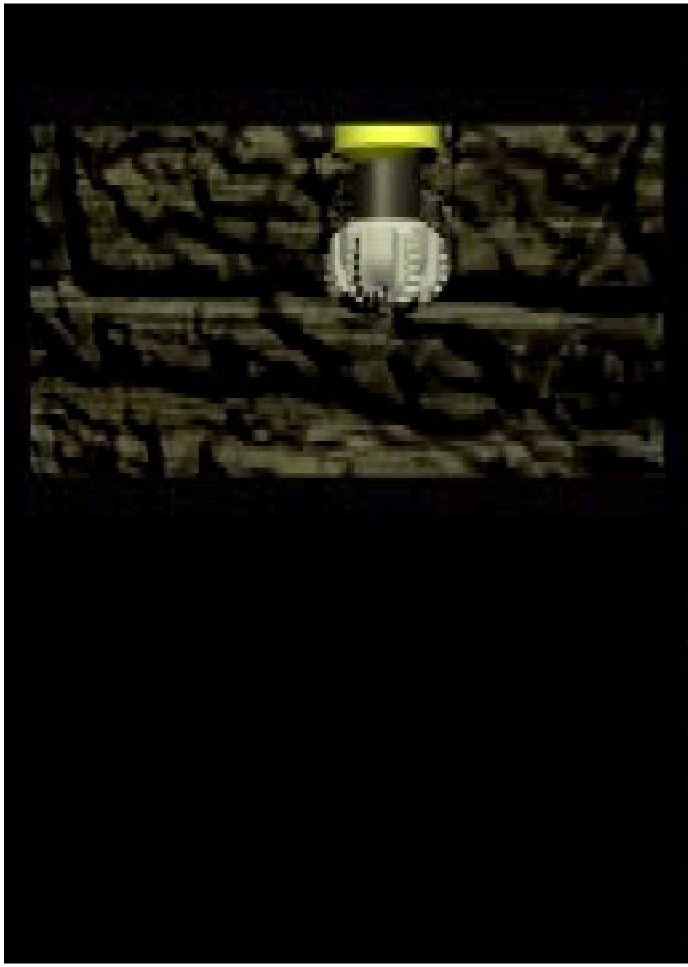
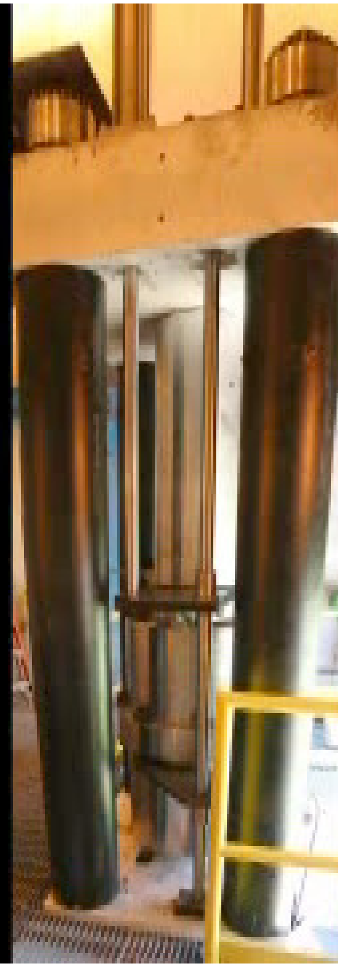
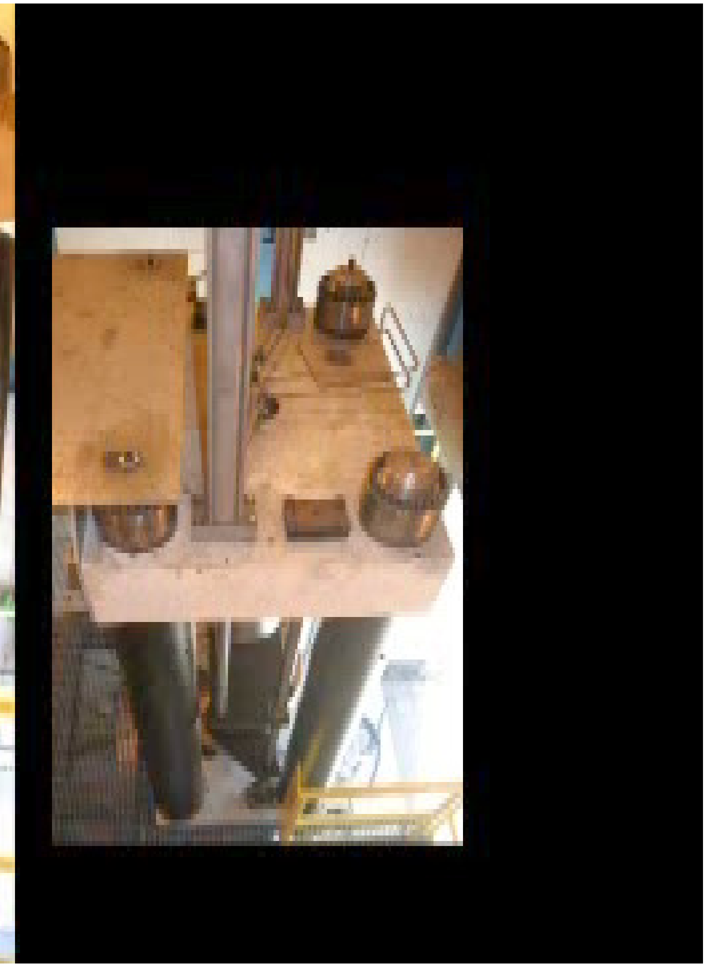
- State-of-art facility
  - Designed with industry input
  - Dramatic expansion of PT envelope
  - X-ray imaging
  - Rock/mud labs
- Single cutter with potential for full bit
- Data for model validation
- Collaborative R&D on drilling dynamics
  - Flexibility to work with others

Key Collaborators

- Schlumberger, Baker Hughes, & ARMA
- U. Utah, CMU, Pitt, WVU, LSU



Ultra-deep Drilling Simulator

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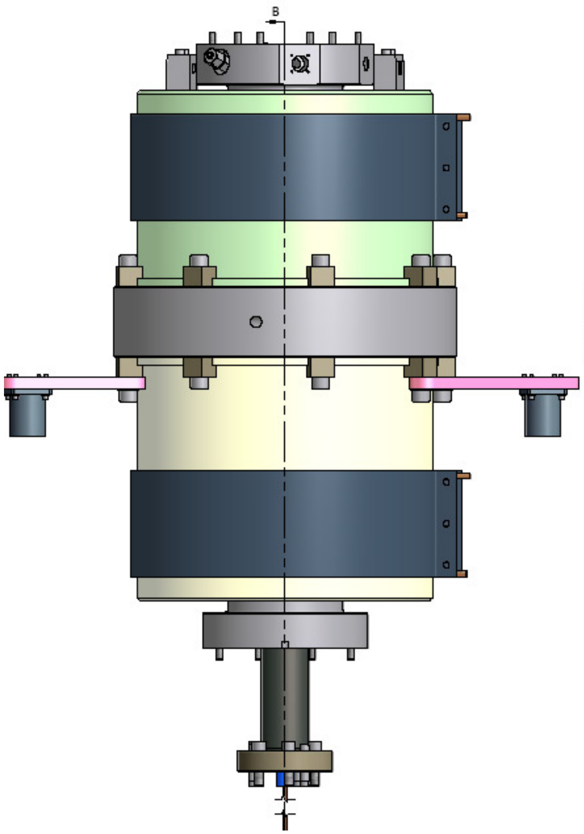
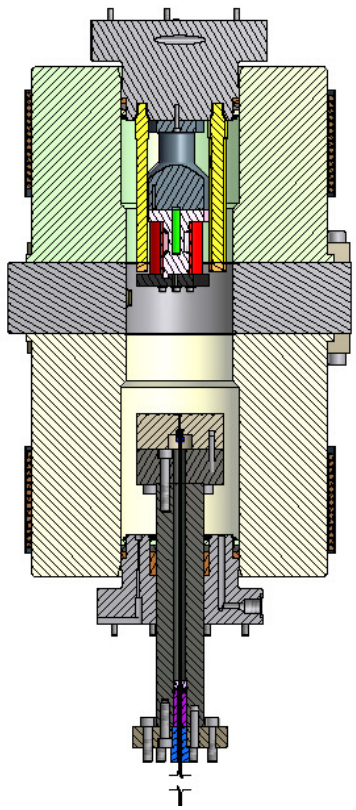




Calendar Year 2009 Objectives

- **Proof test pessure vessel at TerraTek**
  (Completed instead at NETL in March 2009)

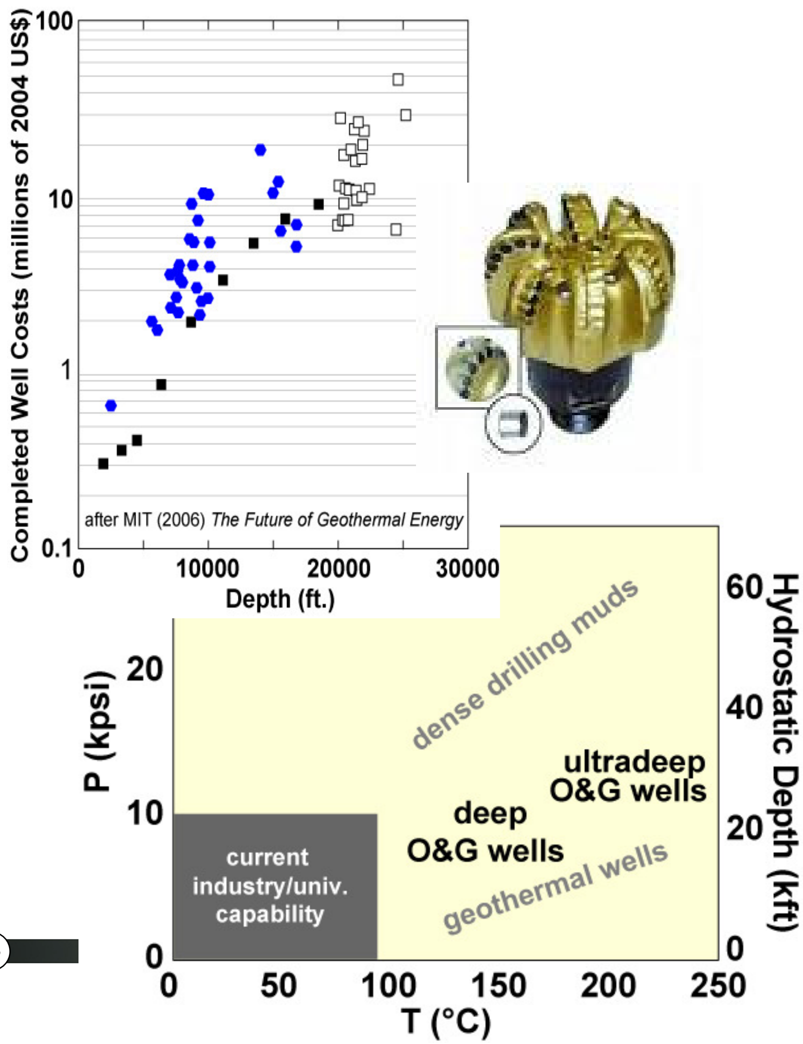
- **Ensure full functionality of UDS at NETL**
  (Underway and expected to be completed by September 2009)
  - Perform series of functionality and shakedown testing
  - Install and shakedown x-ray system

- **Conduct baseline testing**
  (Preparations underway. Objective expected to be completed by December 2009)
  - Validate single-cutter approach with multi-cutter results
  - Extend full bit simulations to elevated T and P
  - Initiate testing of various drilling muds/fluids using model rock systems

- **Establish Industry Working Group**
  (Underway. Initial visit to NETL FY10 Q1/Q2)
  - Generate industry commitment to the XDL
  - Input to future test plans
  - Ensure research meets current industry needs and fills technology gaps

Drilling under Extreme Conditions

Goal: To improve the economics of drilling deep and ultra-deep wells by increasing the rate of penetration and by developing better-performing materials for extreme drilling environments



Four Elements to Research Focus

- Experimental investigation of drilling dynamics ★
  - Ultra-deep Drilling Simulator (UDS) and the Extreme Drilling Laboratory
- Development of predictive models for drilling dynamics
- Development of novel nanoparticle-based fluids for improved drilling ★
- Improvement of materials behavior/performance in extreme environments

★ More detail to follow

Nanotechnology for HTHP Drilling Applications

NETL: Phuoc Tran, Yee Soong
IAES: Minking Chyu, Jung-Kun Lee (Pitt)
Rakesh K. Gupta, Sushant Agarwal (WVU)
Lynn M. Walker, DennisC Prieve (CMU)

Goal

- **To improve the economic viability of drilling for domestic deep and ultra-deep oil and natural gas (under high PT—up to 600 ^{o}F, 40 k psi)**

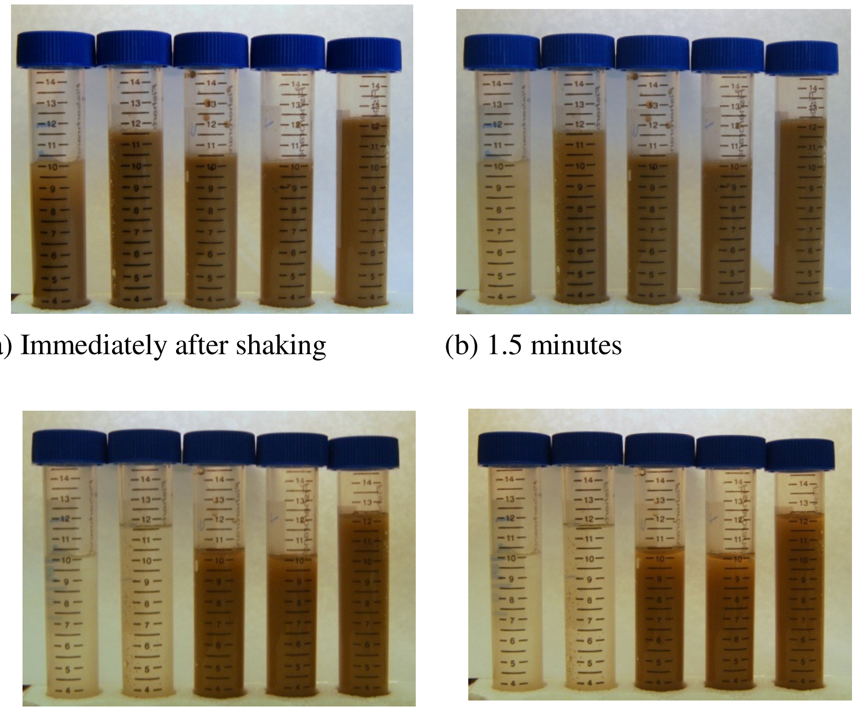
Challenges

- **Currently, polymeric additives are used but they degrade quickly at HTHP**
- **Use of nanoparticles for this application is a new concept, but mechanisms and controlling factors are not known**

Project Objectives

- **Using nanofluids and nanoparticles to tailor transport properties of drilling fluids for oil and gas drilling under HTHP conditions**
- **Two approaches under investigation:**
  - **Nanofluids with commercially available nanoparticles (impact on rheological, thermal, thixotropic properties & stability; haloing)**
  - **Design of new nanoparticles: Cation-exchanged laponite nanoparticles; bentonite–Fe-oxide nanohybrids**

Nanoparticle addition can stabilize barite suspensions.



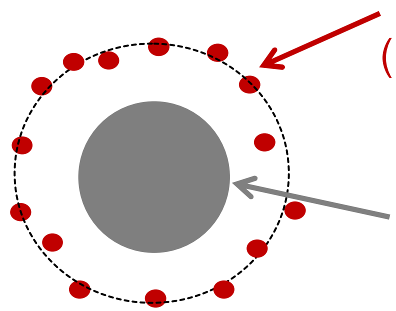
(a) Immediately after shaking (b) 1.5 minutes

(c) 8 minutes (d) 4 hours, 15 min

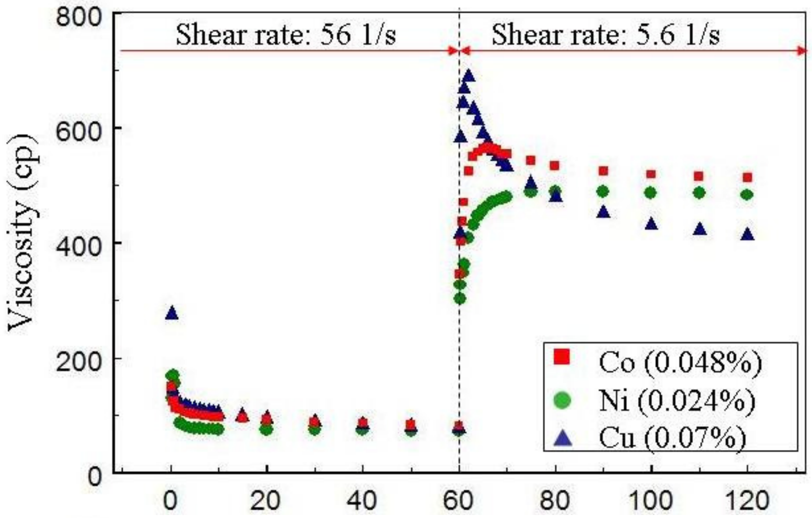
Settling of barite suspensions as a function of time in (from left to right) deionized water, NaOH solution, three different concentrations of silica nanoparticles

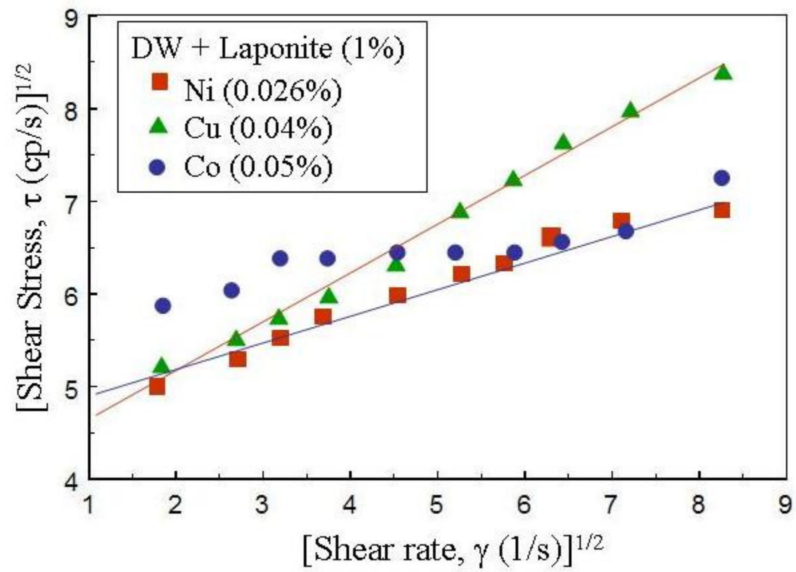
Proposed mechanism:
“Nanoparticle haloing”*

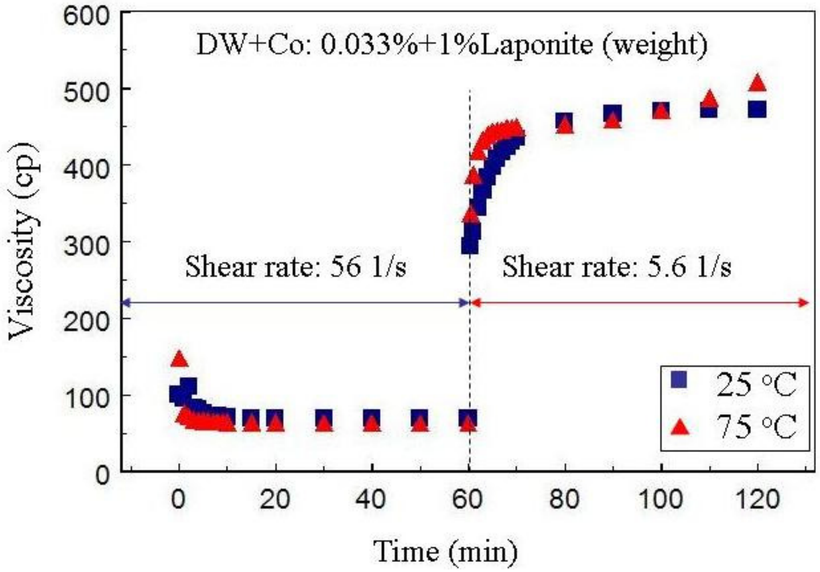
* Tohver et al. (2001) Proc Natl Acad Sci **98:**8950



Nanofluids Containing Cation(metal)-exchanged Laponite Nanohybrids (Prepared via Laser Ablation)

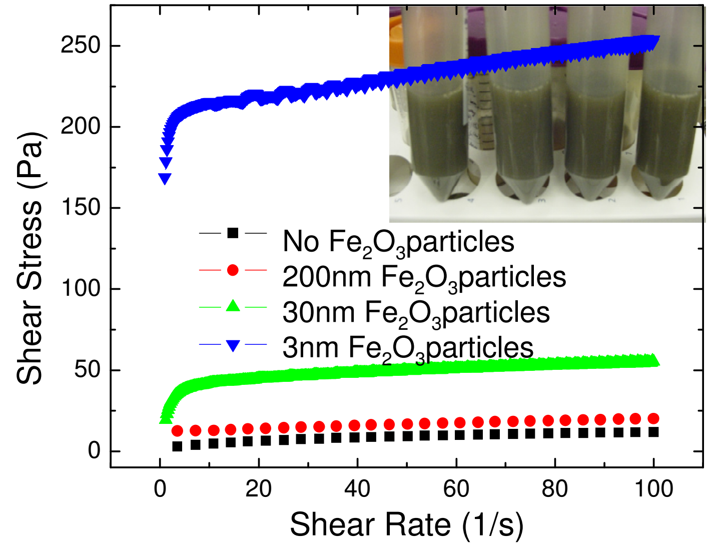




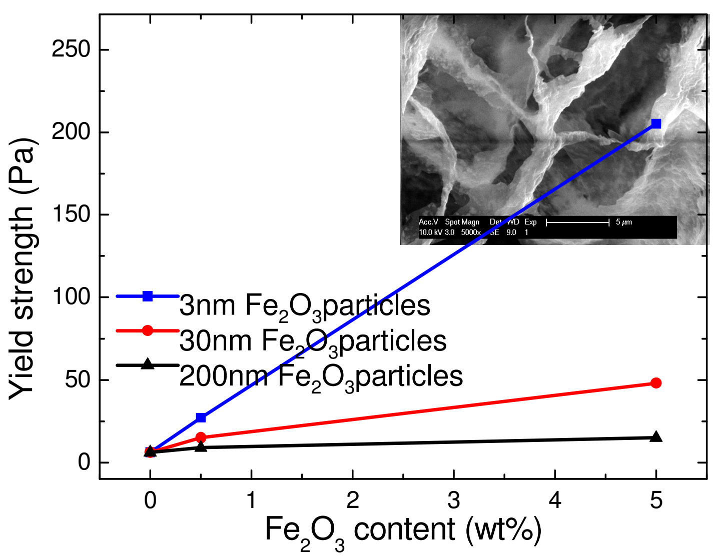


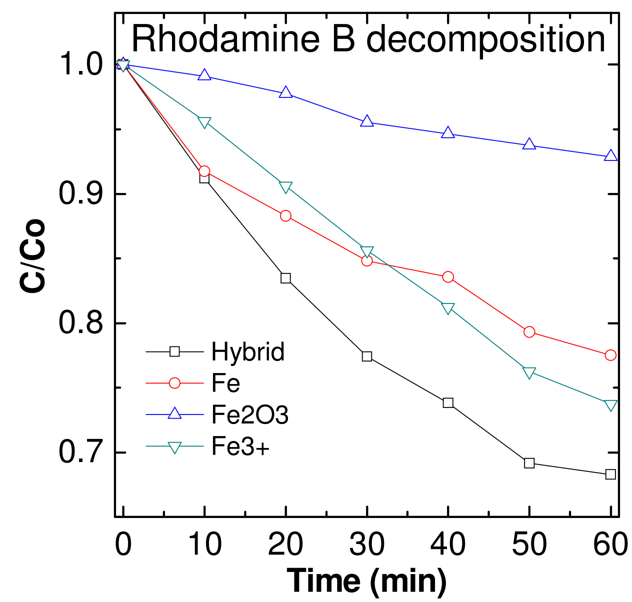
- **Fast gel break down and build up**
- **High gel strength for suspending weighting materials**
  - **2.2 N/m^2 & 1.7 N/m^2 for Ni- & Cu-laponite (barite suspension requires ~0.5 N/m^2**

Hybrid nanoparticle mixtures could lead to tunability.



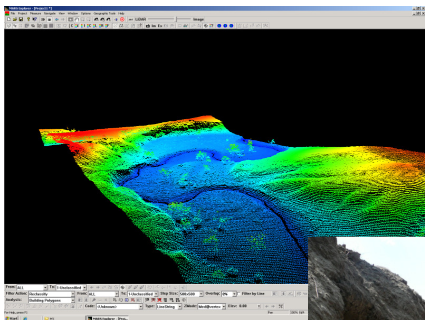
- Create **smart drilling fluids** with high temperature stability and tunable viscosity by adding Fe_2O_3 nanoparticles into clay based fluids.
- Find the **correlation** among **particle size** and **viscosity** in the fluids consisting of Fe_2O_3 nanoparticles and clays.

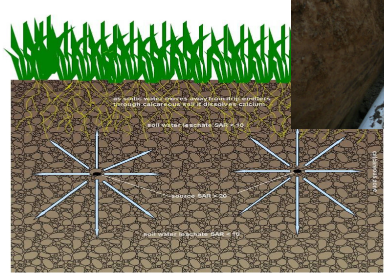




Environmental Impacts of Oil/Gas

Goal: To develop an improved, science-base understanding that leads to solutions for potential environmental challenges to oil/gas production





Major Elements to Research Focus

- **Evaluation of strategies for effective and environmentally sound disposition of produced waters**
  - **Produced water database (PWMIS)**
  - **Evaluation of potential options (subsurface drip irrigation; ephemeral streams)** ★
  - **Quantitative models via a portfolio of monitoring options (airborne, UAV, hyperspectral, electromagnetic, LIDAR, etc.)**
- **More accurate assessment of air-quality impacts by detailed measurement and improved computational representations**
- **(Fundamental inorganic and organic geochemistry of reservoir fluids—including natural background vs. production)**

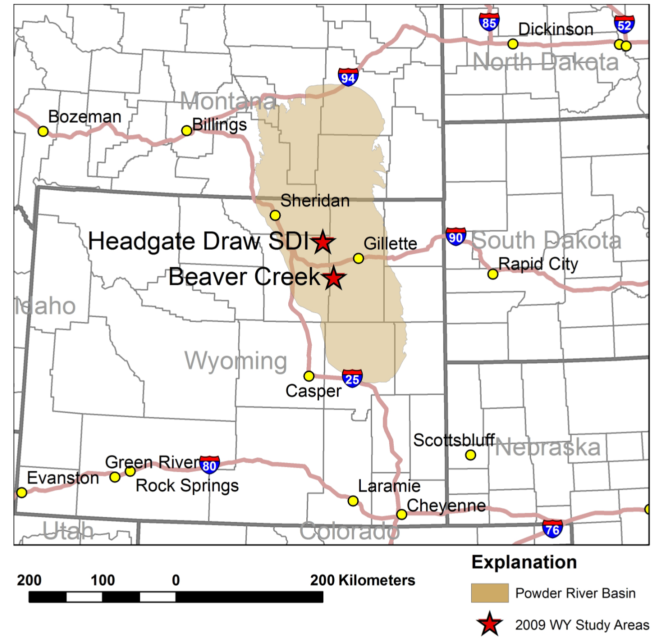
★ More detail to follow

Novel Uses for Produced Waters

Subsurface Drip Irrigation

Goal

- To develop environmental science base for assessing novel approaches to produced waters, including use of CBNG water in subsurface drip irrigation (SDI)



Challenges

- High sodium content impacts soil structure and chemistry

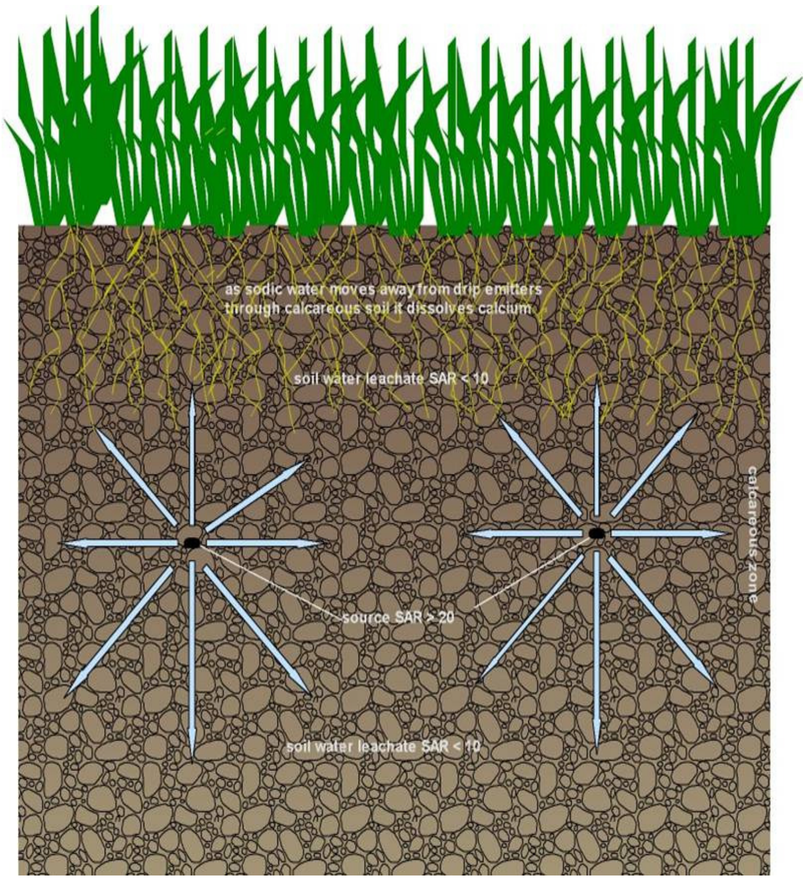
Key NETL Capabilities and Facilities

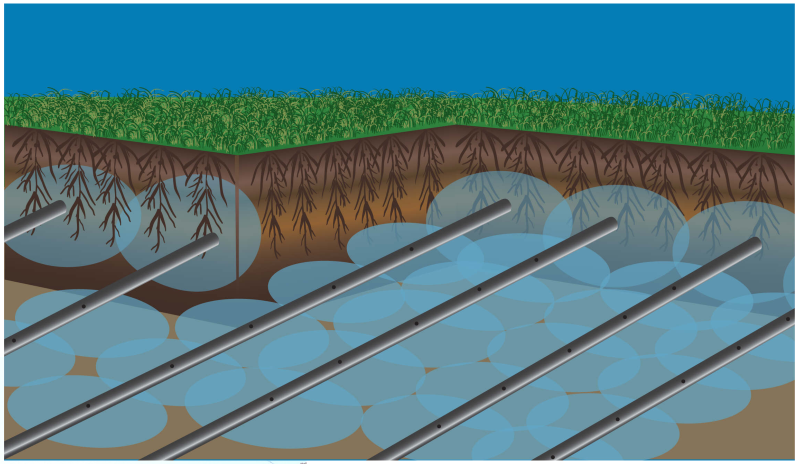
- Airborne and ground-based electromagnetic surveying, hydrology, and geochemistry

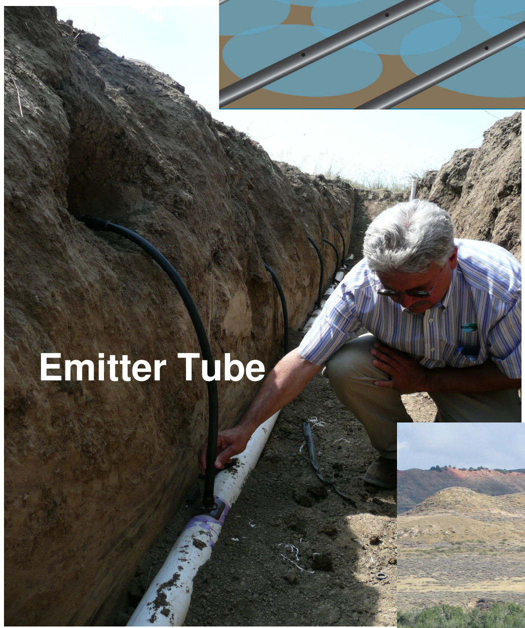
Key Collaborations

- USGS
- BeneTerra LLC (CRADA partner, agronomy, soil science)
- Wyoming DEQ
- Anadarko (CRADA partner, funding and site access)

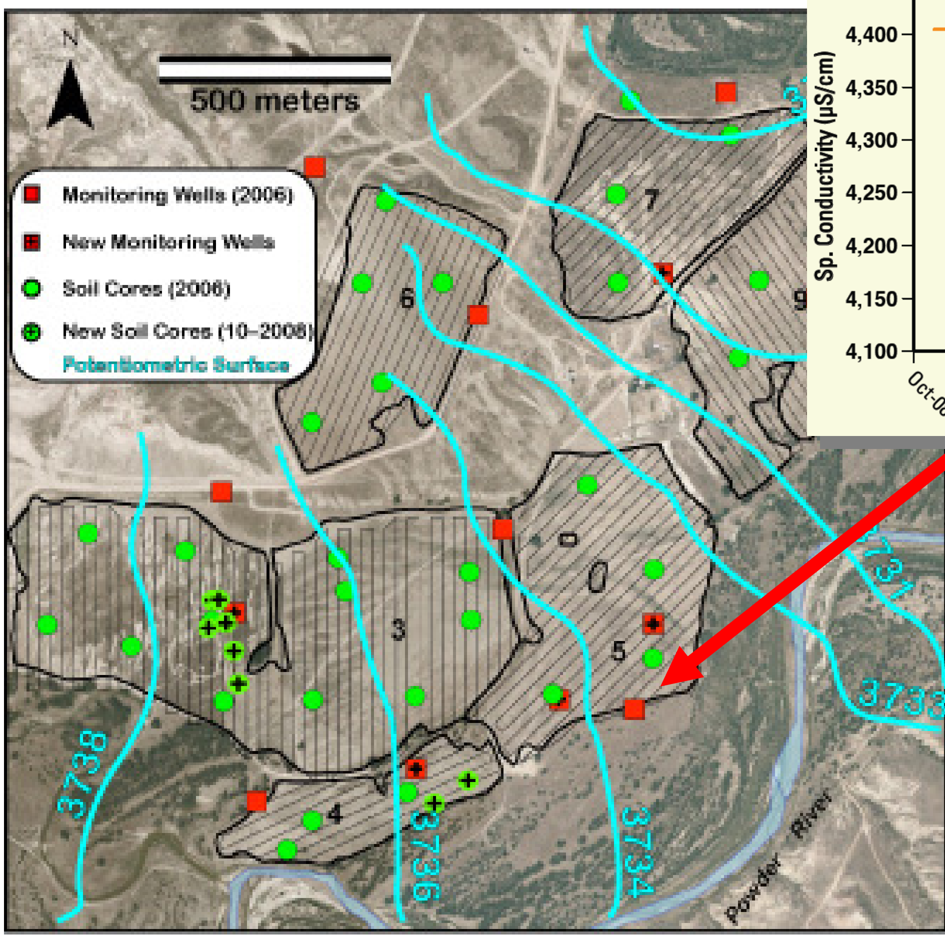
Subsurface Drip Irrigation-Installation

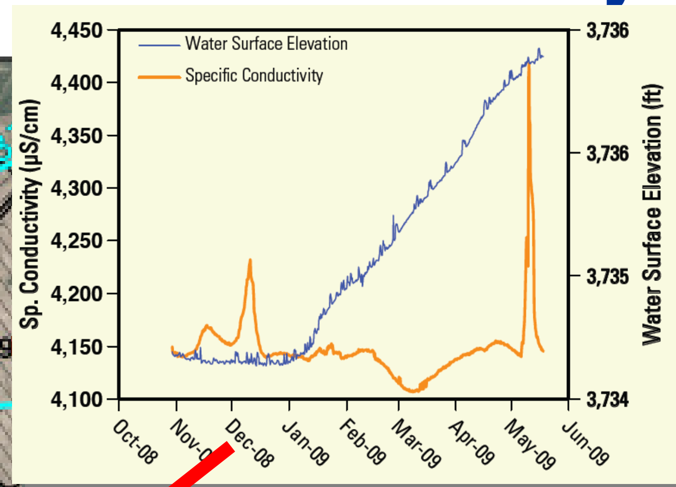


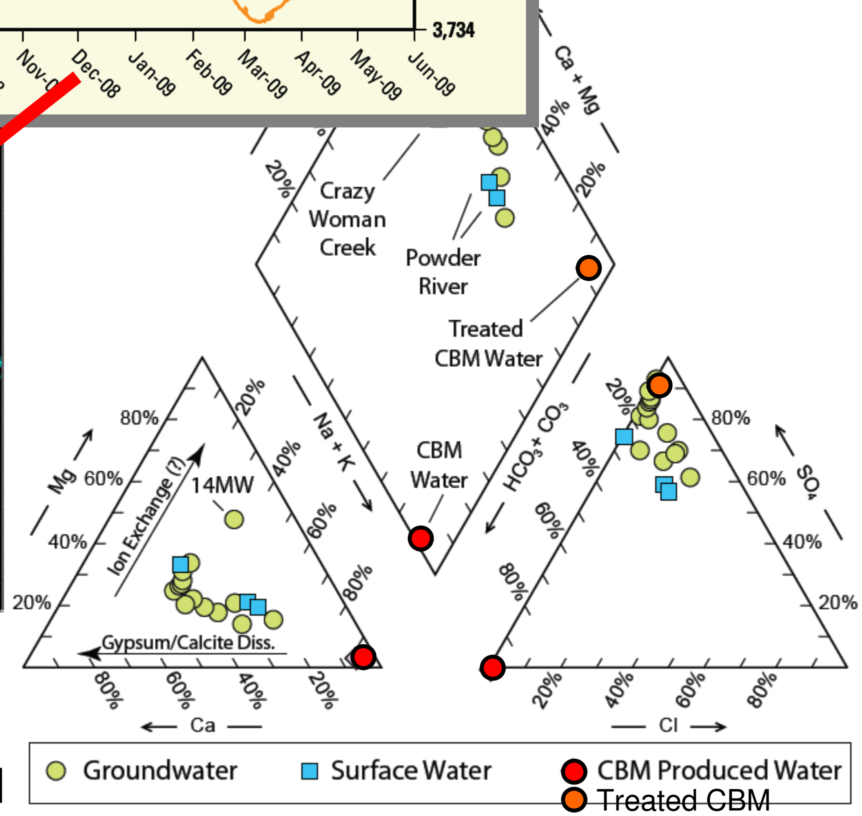




SDI Monitoring and Groundwater Hydrology



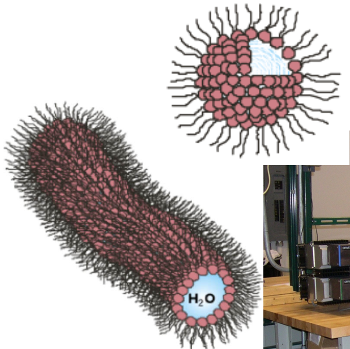


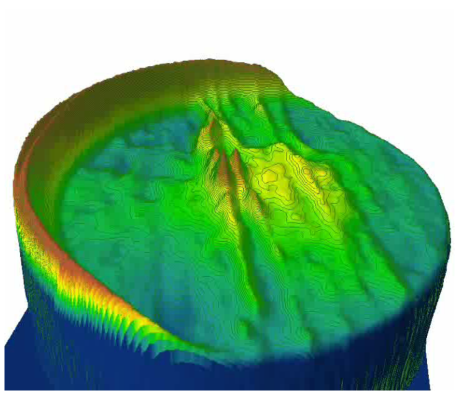


- **Good baseline data; SDI initiated 10/08**
- **Initial monitoring encouraging**
- **5-yr (or steady state) monitoring planned**

Unconventional Oil & Enhanced Oil Recovery

Goal: To enable broader utilization of domestic fossil resources through improved efficiency and lowered environmental impact





Elements to Research Focus

- **CO_2-enhanced oil recovery: Improved flow control by increasing CO_2 viscosity (tailored surfactants)** ★
- In-situ production of oil shale: Improved heating of kerogen by tuned microwave and CO_2
- **Oil production in fractured media: Improve accuracy/reliability of predicting primary–tertiary oil recovery in shale**
- **Catalog experience/knowledge from oil-shale and tar-sand activities**
- **(EOS for CO_2-brine-hydrocarbon at elevated PT)** ★

★ More detail to follow

Control of CO_2 Viscosity for EOR

NETL: Yee Soong

IAES: Bob Enick (Pitt) (J. Eastoe, U. Bristol; design/synthesis of CO_2 thickeners)

Goal

- **To reduce the mobility of CO_2 in porous media by adding a CO_2-soluble surfactant that either (a) thickens CO_2 or (b) forms CO_2-in-brine foams**

Challenges

- **Low viscosity of CO_2 inhibits efficient sweep of reservoir**
- **Difficult to dissolve surfactants in CO_2 at MMP because they must contain CO_2-phobic segments and CO_2 is a feeble solvent**
- **Even more difficult to tailor the surfactant either to form rodlike micelles or to stabilize CO_2-in-brine emulsions**

Project Objectives

- **To identify inexpensive, environmentally benign, CO_2-soluble surfactants that are capable of lowering the mobility of CO_2 in cores**
- **FY09: To identify surfactants that demonstrate proof-of-principle**

State of Science

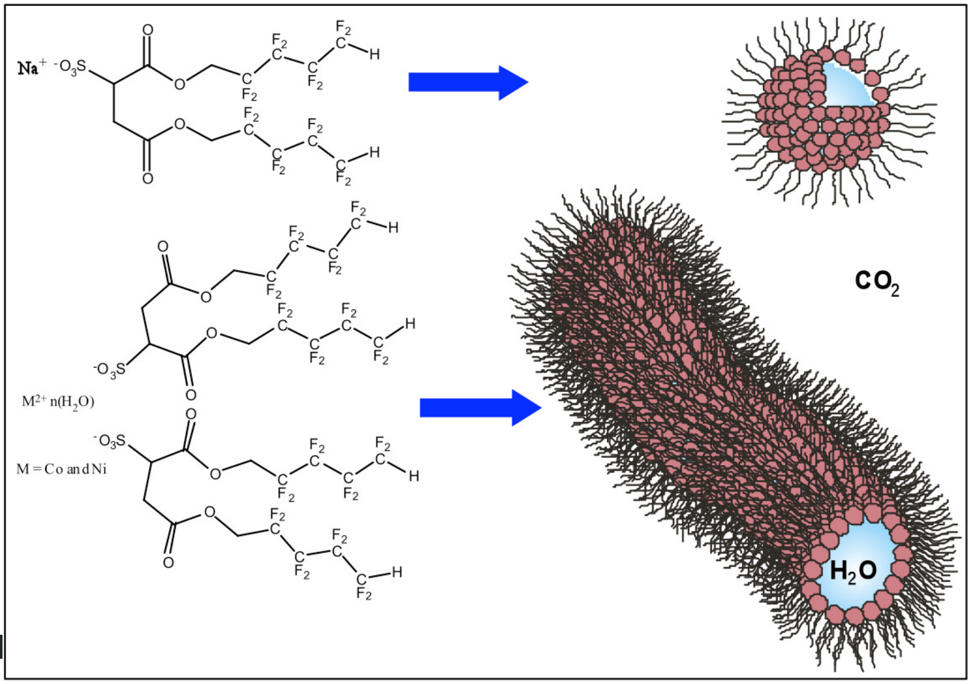
- **No other group is working on direct thickeners for CO2**
- **DOW has a new proprietary CO_2 foam-forming surfactant** [1,2]

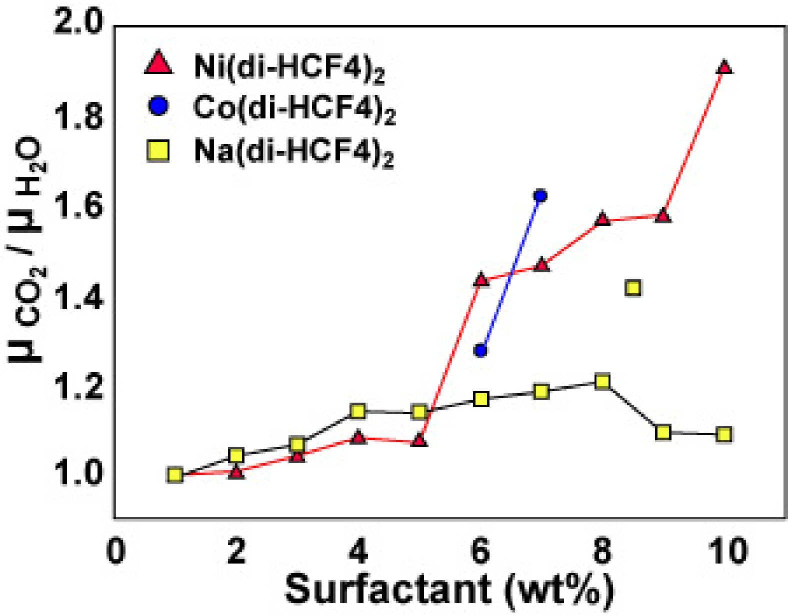
(1) Le, Nguyen, Sanders, SPE 113370, 2008 SPE/DOE IOR Symp.; Tulsa, OK; April 2008
(2) Dhanuka, Dickson, Ryoo, Johnston; J. of Colloid and Interf. Sc.; 298 (2006) 406-418

Accomplishments

- **Demonstrated that viscosity-enhancing rodlike micelles can be formed in CO_2**
  - **Now trying to design an affordable, non-fluorous surfactant that can do so in dilute concentration at MMP**

- **Identified two commercially available, CO_2-soluble, very water-soluble, nonionic surfactants (DOW Tergitol NP9, BASF Lutensol XP70) and demonstrated that they can stabilize CO_2-in-brine emulsions (data not shown)**

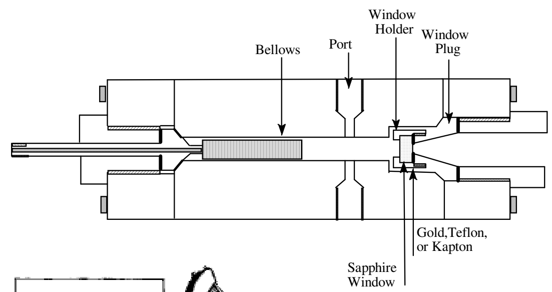




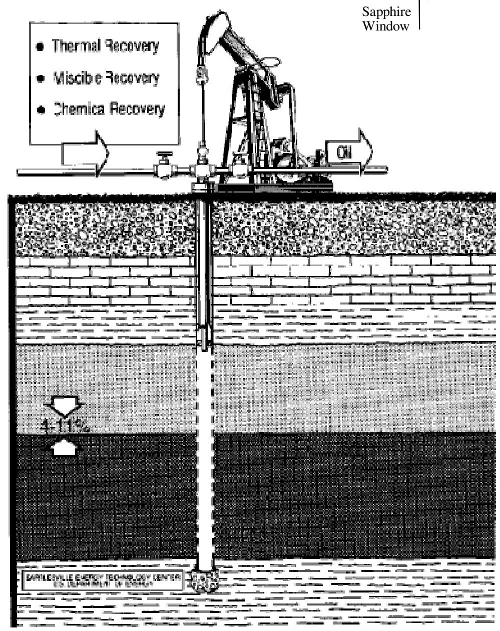
SANS data verify that micellar shape for Ni- and Co-$(di\text{-}HCF4)_2$ is rodlike, whereas Na-(di-HCF4) forms spherical micelles.

Equation-of-State Modeling for Extreme Geological Conditions

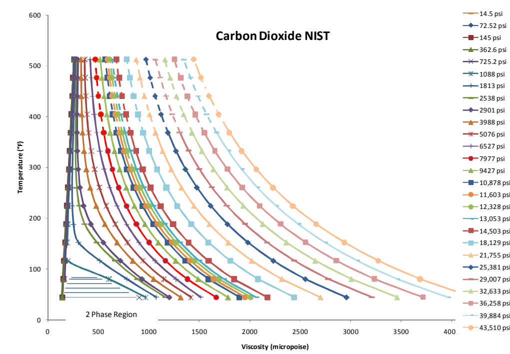
- **Combine PVT and PVTμ literature data with a focused experimental program to create a comprehensive database that is required to develop PVT-EOS**
  - 500°F, 40kpsi
  - Phase comp., number of phases, ρ, C_p, H, μ, k



- **Applicable to geological sequestration as well as oil and gas production**



- **Improved EOS models will allow**
  - Increased production
  - Increased efficiency
  - Improved safety and environmental performance



$$T = \frac{C(\lambda)P}{\mu - b(T)} - \frac{a}{\mu^2 + \alpha b\mu - \beta b^2}$$

Questions