NATIONAL ENERGY TECHNOLOGY LABORATORY

Title IX, Subtitle J (EPAct 2005) Complementary Program - Office of Research and Development

September 2008

Complementary Program NETL - ORD

- **Areas of research**
  - Drilling Under Extreme Conditions
  - Environmental Impacts of Oil and Gas
  - Enhanced and Unconventional Oil Recovery
  - Resource Assessment
- **Institute for Advanced Energy Solutions**
  - West Virginia University, Carnegie-Mellon University, and University of Pittsburgh
    - Penn State University and Oregon State University

Drilling Under Extreme Conditions

- **Ultra-deep single cutter drilling simulator**
  - Recreates bottom-hole drilling environment of ultra-deep wells (30,000 psi and 481°F)
  - Delivered to NETL later this year
  - Operates with real drilling fluids
  - X-ray video system images cuttings
  - Verify the results of the full bit simulator performance at 10 ksi performed by TerraTek
    - Extend their results by performing tests up to 30 ksi
  - Use discrete element modeling approach to incorporate loading on the drill bit generated by the rock cuttings

Fabrication at TerraTek

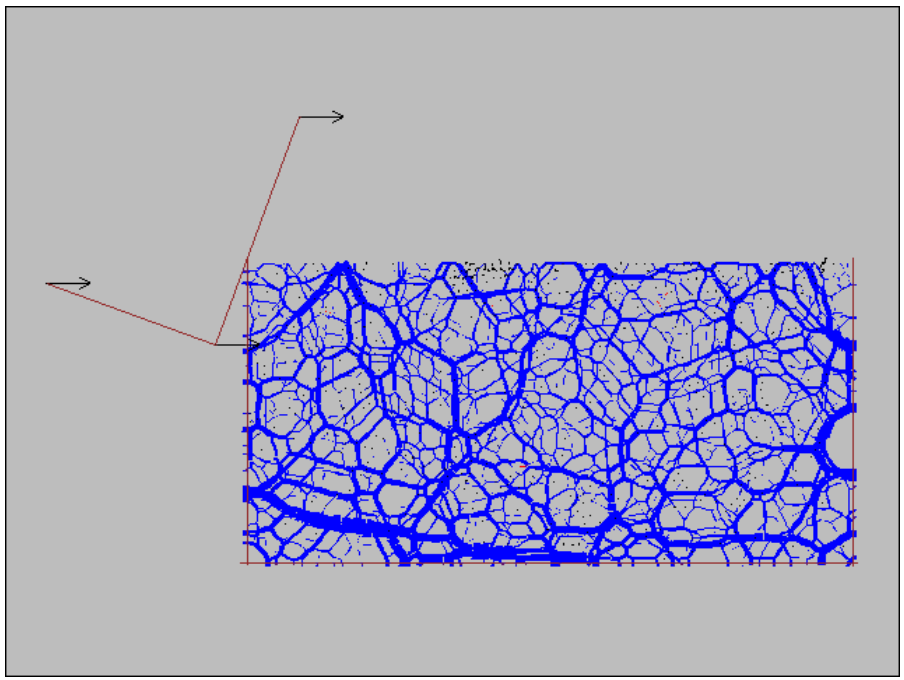
EDL Supporting Instrumentation

- **Integration of an Abrasive Water Jet Cutter into lab for optimal sample prep**
  - Prepares defect-free rock samples
  - Able to cut small samples from sample for microscopic examination

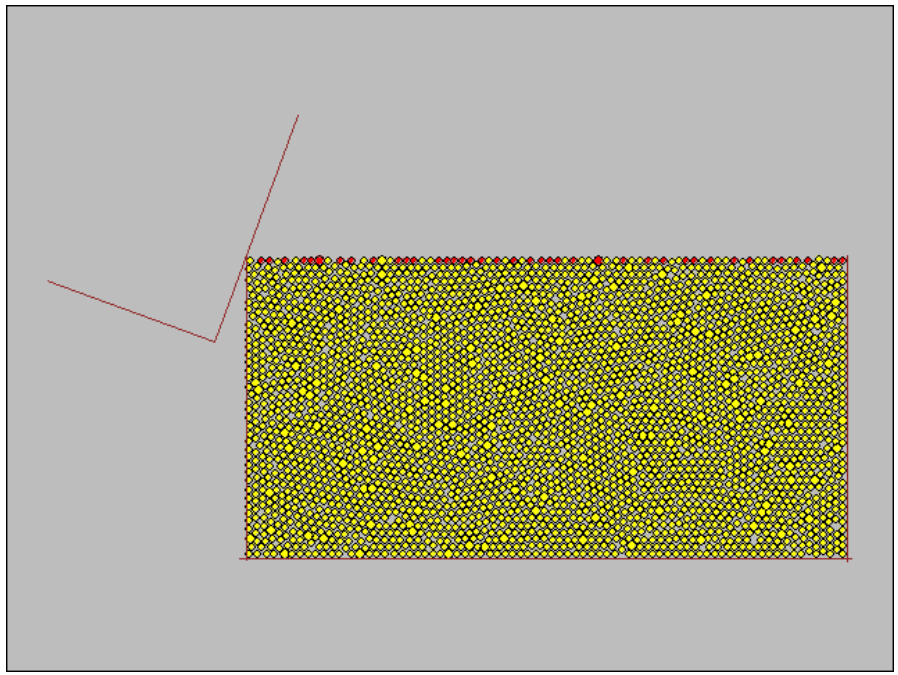
- **Integration of a Confocal Laser Scanning Microscope for pre-test & post-test rock analysis**
  - Optical resolution to 120 nm (xy plane)
  - Optical resolution to 10 nm (z axis)

- **Integration of Chandler Model 7600 viscometer for HPHT rheology measurements**
  - Quantify drilling fluid properties at UDS test conditions

Initial Discrete Element Method Modeling Result -Trial Run of PFC2D



Blue: compression force chain
Red: tension force chain
Initially in isotropic compression. As cutter moves in, more area is affected.



Particle movement as cutter advances. The segmentation pattern is a function of the stress level and bond characteristics.

DUEC – Materials/Sensors

- **HPHT materials development and performance**
  - Obtain field samples that have failed under HPHT drilling conditions (primary source: RPSEA members)
  - Determine HPHT failure mechanisms and develop a laboratory evaluation technique
  - Improve resistance to corrosion, wear, corrosive wear and fatigue.
    - Cylinder-on-anvil apparatus for wear/corrosion testing
  - Develop laboratory scale tests that accurately predict performance in HPHT conditions.
  - Develop low cost coatings for Fe alloys used in drill pipe-casing systems
  - Application of computational approaches for developing alloys resistant to fatigue under extreme drilling conditions (Jamie Kruzic, Oregon State University (OSU))
  - **Ultimate goal: New alloys for drilling, completion, and production in HPHT environments**

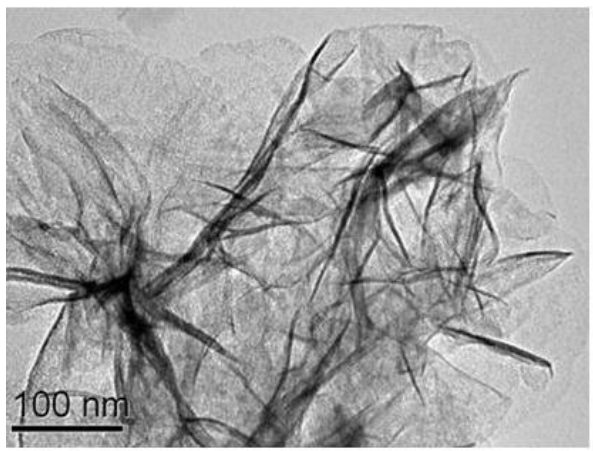
Cylinder-on-anvil apparatus

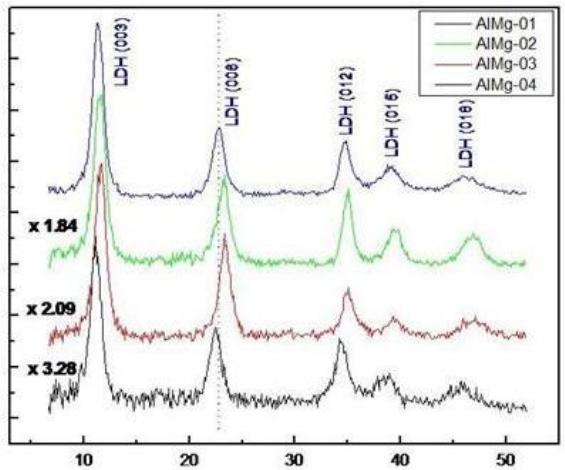
Sensor development (CMU)

- **Initiated SiC electronics for deep drilling**
  - Design a HT operational amplifier or oscillator prototype
  - Fabricate via Cree SiC process

Nano-fluids for Oil and Gas Applications

- **Laser synthesis and characterization of (Mg-Al) layered double hydroxides (LDHs) nanostructures and other nano-materials (Al, Mg, Fe, Ni, Cobalt, ...)**
  - Determine ablation and laser conditions for morphology, structures, surface functionalization
  - Optimize ablation rate
- **Test for application as drag reduction, drilling fluids, fracturing fluids, or as a drilling fluid enhancer**





$Mg_6\ Al_2\ (OH)_{18}\ 4.5\ H_2O$ nano-structure

Drilling Under Extreme Conditions
FY09 Plans

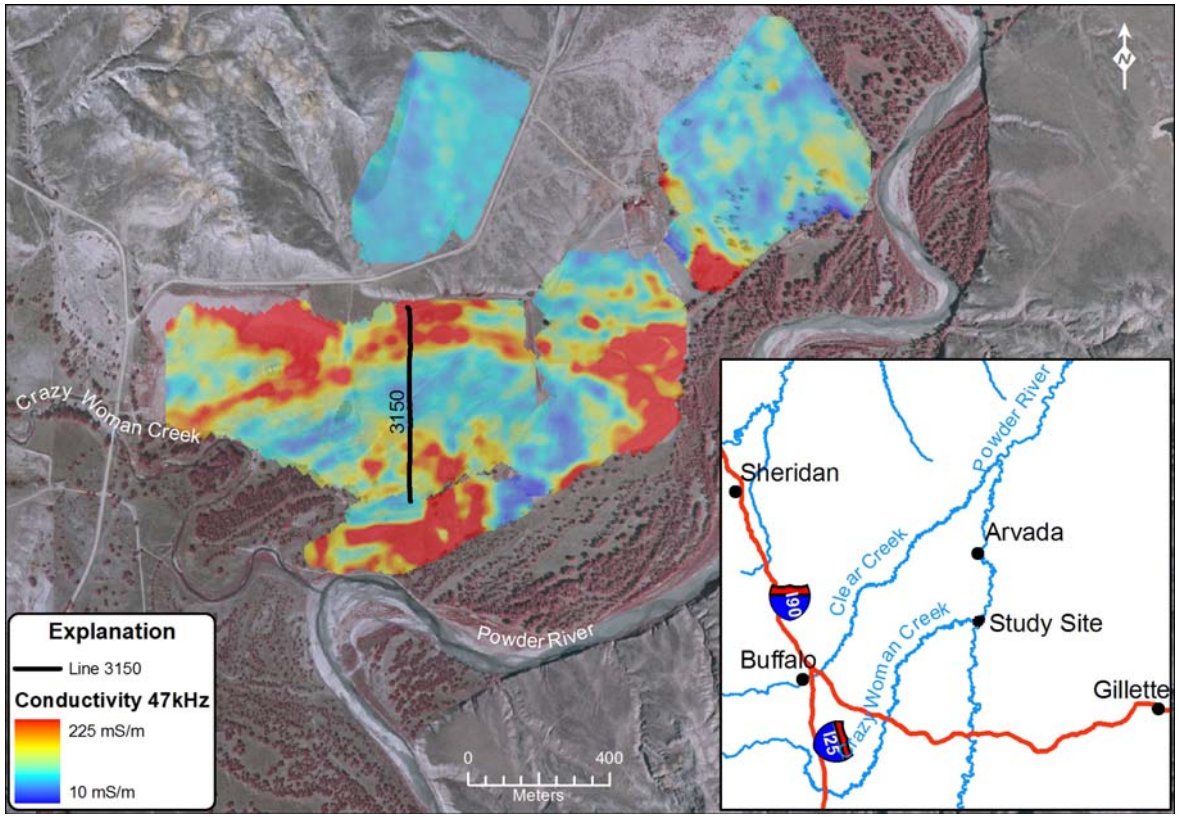
- **Incorporate various modeling activities into Extreme Drilling Lab activities**
  - Debug UDS to full design capabilities
  - Calibrate Models
  - Modelers to suggest test plans to prove hypothesis routed in numerical modeling results.
  - Seek out optimal placement / characteristics of drilling fluid around the cutter-rock interface.
- **Identify failure mode of commercial HPHT materials**
- **Produce sufficient quantities of nano-fluids for characterization**

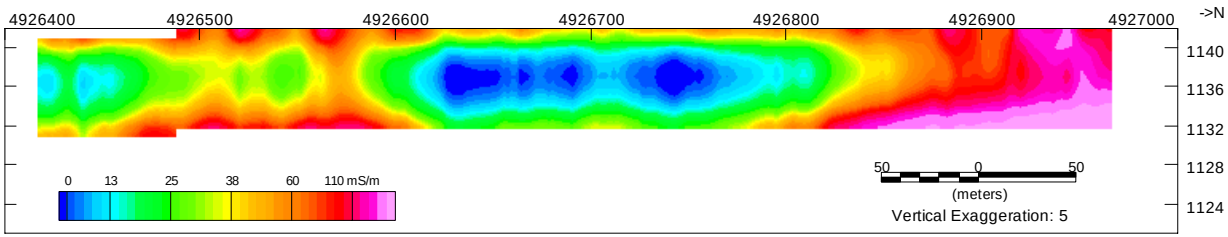
Environmental Impacts of Oil and Gas E&P

- **Produced water management efforts are a subset of the DOE HQ strategic O&G Water Initiative**
- **Evaluate Subsurface Drip Irrigation as a means of using CBNG produced water**
  - Long-term effect on soil productivity
  - Accumulation or mobilization of salts
  - Effect on native groundwater
  - Discharge to Powder River
  - Collaborating with Anadarko Petroleum at Headgate SDI Site - Operated by Beneterra, Inc.
- **Conduct a long-term, science-based assessment**
  - Electromagnetic surveys useful for SDI design
  - Monthly geophysical surveys to trace movement of SDI water
  - Monthly sampling of vadose and phreatic zone
  - Continuous monitoring of groundwater temperature, conductivity, and water table elevation

Electromagnetic surveys

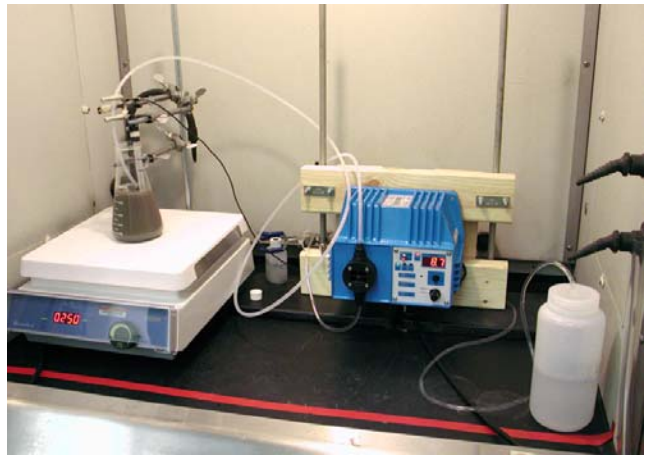
Electromagnetic Induction Survey





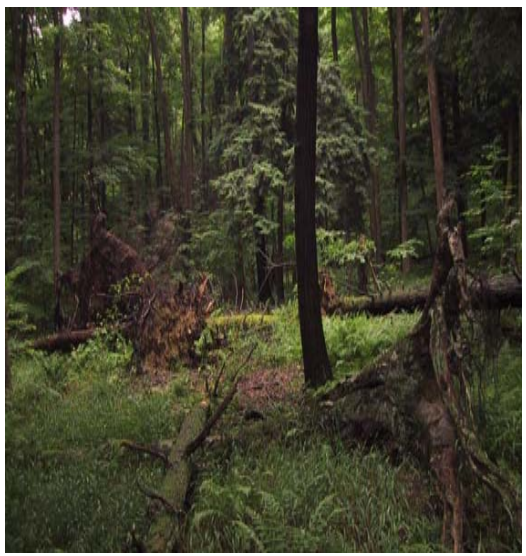
Environmental Impacts of Oil and Gas E&P

- **Develop methods for determining suitability of ephemeral stream courses for CBNG produced water**
  - Airborne electromagnetic, and spectral surveys of Beaver Creek watershed (WY)
  - Evaluate results of stirred batch leaching tests
  - Protocol for estimating amount of produced water that can be discharged before flooding/erosion occurs
- **Environmental assessment of next generation oil shale retort technologies (WVU)**
  - Determine O&G E&P impacts on stream ecology in Allegheny National Forest
  - Work with PA Dirt and Gravel Road Program to develop O&G road construction protocol
- **Minimize environmental footprint of E&P from Marcellus Shale gas play**
  - Apply methods used elsewhere to minimize environmental impact (multiple wells from single pad, frac farms)



Environmental Impacts of Oil and Gas

- **Effects of oil and gas E&P on air**
  - Assess air quality based on measured data and modeling results for regulatory and permitting applications
  - Source-receptor/pollutant transport models
- **Challenges**
  - Estimates of air quality impacts of oil and gas production are generally based on models that treat all development in a state as a single point source
  - Emissions from oil and gas production activities vary by type of activity and there are a wide range of pollutants



- Allegheny National Forest
- 512,998 acre forest in northwestern PA
- 8,000 wells in 2005; currently 12,000
- Western site - TBD

Air Quality Model Selection

Source-Receptor Model:
Positive Matrix Factorization (PMF)

$$x_{ij} = \sum_{h=1}^{p} g_{ih} f_{hj} + e_{ij}$$

x = data matrix of *i* species and *j* days
g = compositions for *h* sources
f = contributions of *h* sources
e = error matrix
p = number of sources

Pollutant Transport Model: The Comprehensive Air quality Model with Extensions (CAMx)

- **Eulerian photochemical dispersion model**
- **Gaseous and particulate air pollutants (ozone, $PM_{2.5}$, PM_{10}, air toxics, etc.)**
- **Uses any meteorological model in combination with any emissions processor**

Environmental Impacts of O&G – FY09 Plans

- **SDI - Complete 2 semi-annual well samplings and geophysical surveys**
- **Establish Eastern air quality monitoring station**
- **Prepare report on environmental impact of emerging oil shale technologies**
- **Proof of concept flights completed for drones**
- **Summarize findings from 1st year of monthly macroinvertebrate sampling at impacted and non-impacted streams**

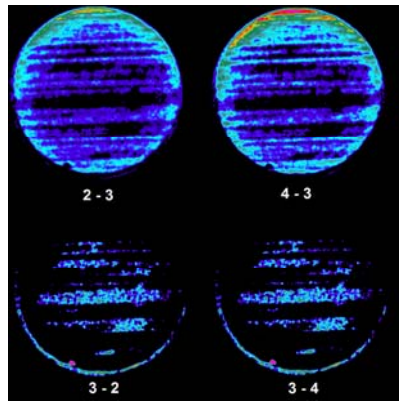
Enhanced and Unconventional Oil Recovery

- **Technical challenges**
  - Difficulty in characterizing fracture properties (e.g., orientations, lengths, apertures) that control flow
  - Two-phase transport properties of fractures themselves are not well-understood
  - As pressures in a reservoir change, fractures may open and close; this behavior is complex
  - Using an injectant in a fractured reservoir may be problematic because of the propensity for fast paths to be established; an understanding of the interaction between fluids in fractures and matrix rock should help the design of better recovery schemes

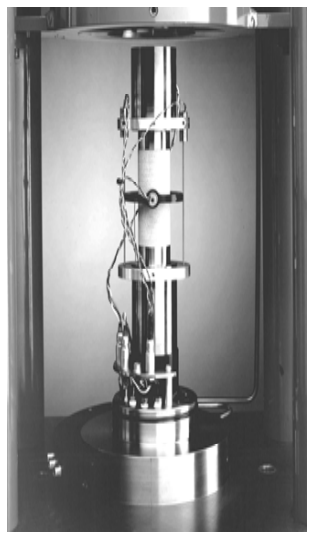
Microscopic Image of Fracture Surface

EUOR Simulations Methodology

- **Build on background research on fractured reservoir flow**
- **Integrate information from laboratory, field work, and simulations**
- **Collect information from geologic logs and other collected info to build model of Bakken**
- **Make measurements of shale properties (geomechanical and flow)**
- **Simultaneously develop technique to use neural nets to describe fractured reservoirs**
  - FRACGEN/NFFLOW



CT Scanner used to characterize fractures and track fluid flow



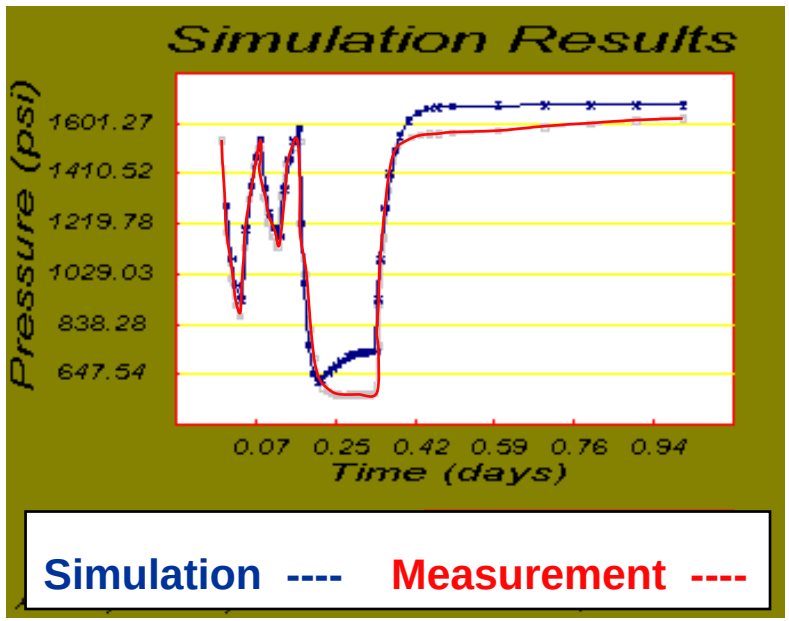
Reservoir Rock Core Flow Unit

FRACGEN/NFFLOW

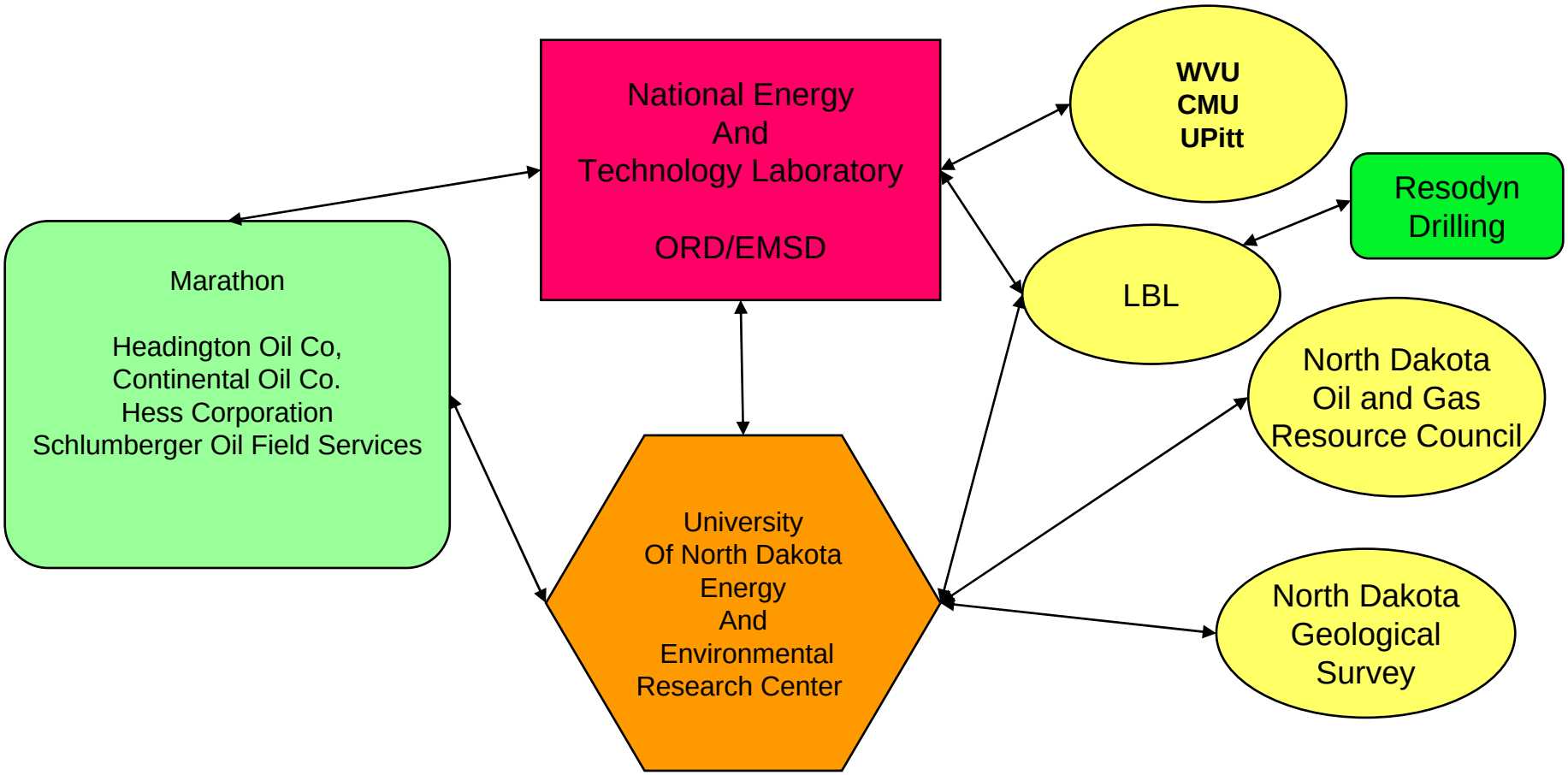
- **FRACGEN uses field data to characterize statistics of fracture networks**
  - Well log
    - Fracture orientation, aperture, and density statistics
  - Outcrops
    - Clustering and fracture length statistics

- **NFFLOW is a flow simulator for highly fractured reservoirs**
  - Explicitly treats fracture networks with < 50,000 fractures
  - Couples fracture flow with recharge from surrounding rock
  - Handles gas or liquid

Well test data from gas field



Bakken Shale Team



Enhancing Oil Mobility

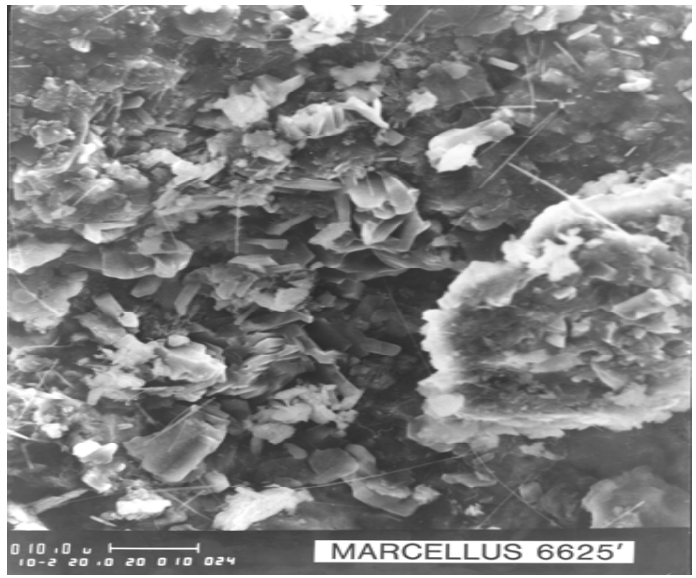
- **Strategies for employing novel surfactants**
  - Design CO_2-soluble surfactants that form foams or viscosity-enhancing micelles
  - Design water-soluble surfactants that form high CO_2 volume microemulsions
- **FY09 effort focuses on surfactants that increase CO_2 viscosity (Pitt)**
  - Promote formation of helical micelles that induce large increases in viscosity

EUOR FY09 Plans

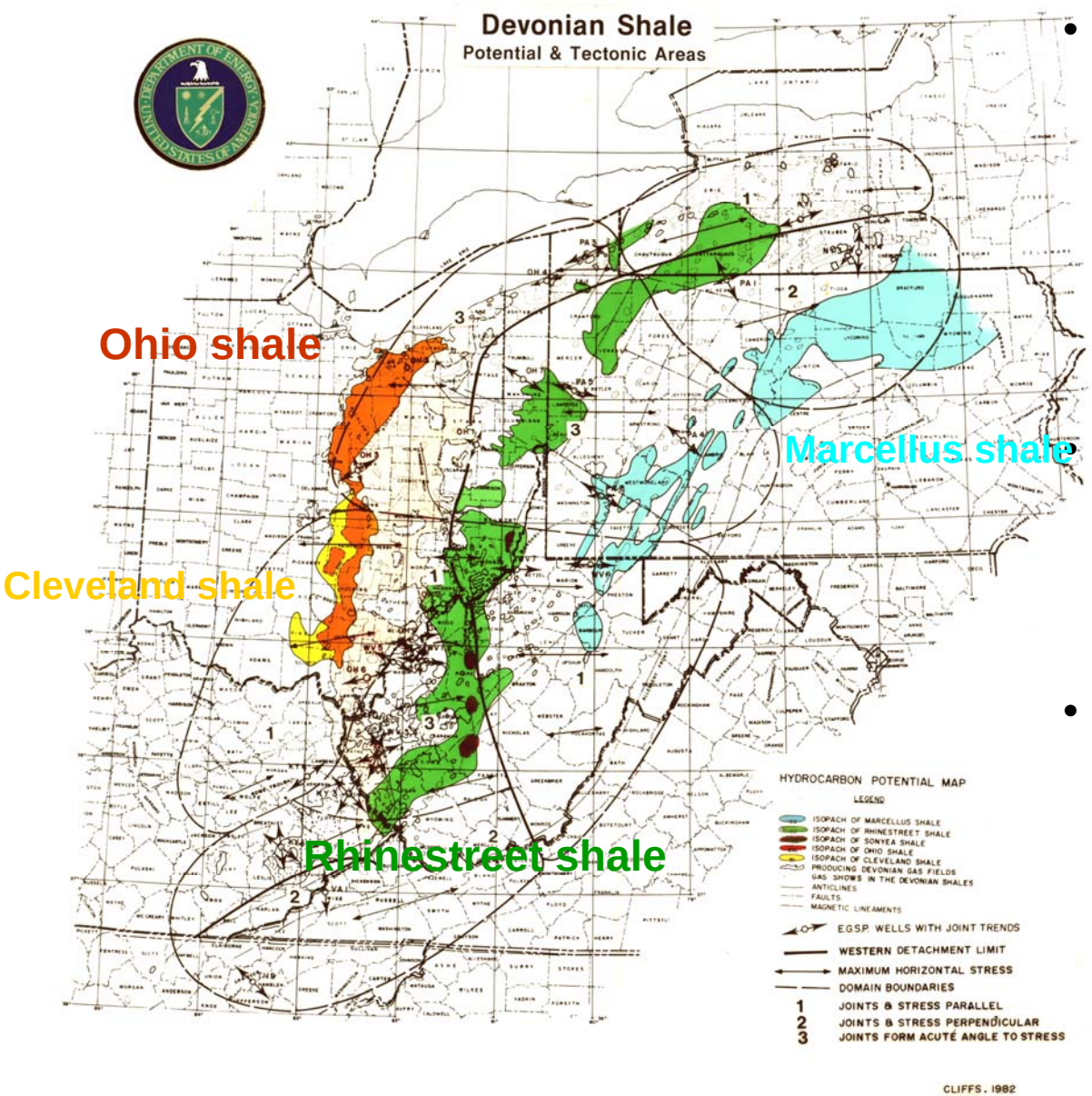
- Perform tests for transport properties on Bakken shale cores
- Conduct initial reservoir simulation for a fractured reservoir with available field data
- Measure viscosity of CO_2-surfactant solution using the falling cylinder apparatus
- Complete design package and preliminary cost estimate for proof-of-concept test unit for CO_2-enhanced in situ oil shale conversion

Resource Assessment

- **Create a database of oil shale and tar sand documents for future use**
  - 18000 reports on microfiche
- **Resource characterization of the potential gas-in-place in Marcellus Shale (PSU/WVU)**
  - Initiated core, well log and geological data acquisition to characterize the shale formation
  - Characterization instrumentation is being upgraded
  - Collect info from previous studies on Devonian shale formation above Marcellus
  - Database being developed



Marcellus shale



- DOE and GRI characterized Devonian Shale over the last 30 years
  - -Marcellus Shale is the oldest and deepest of the formations
  - -Lack of well and reservoir characterization data

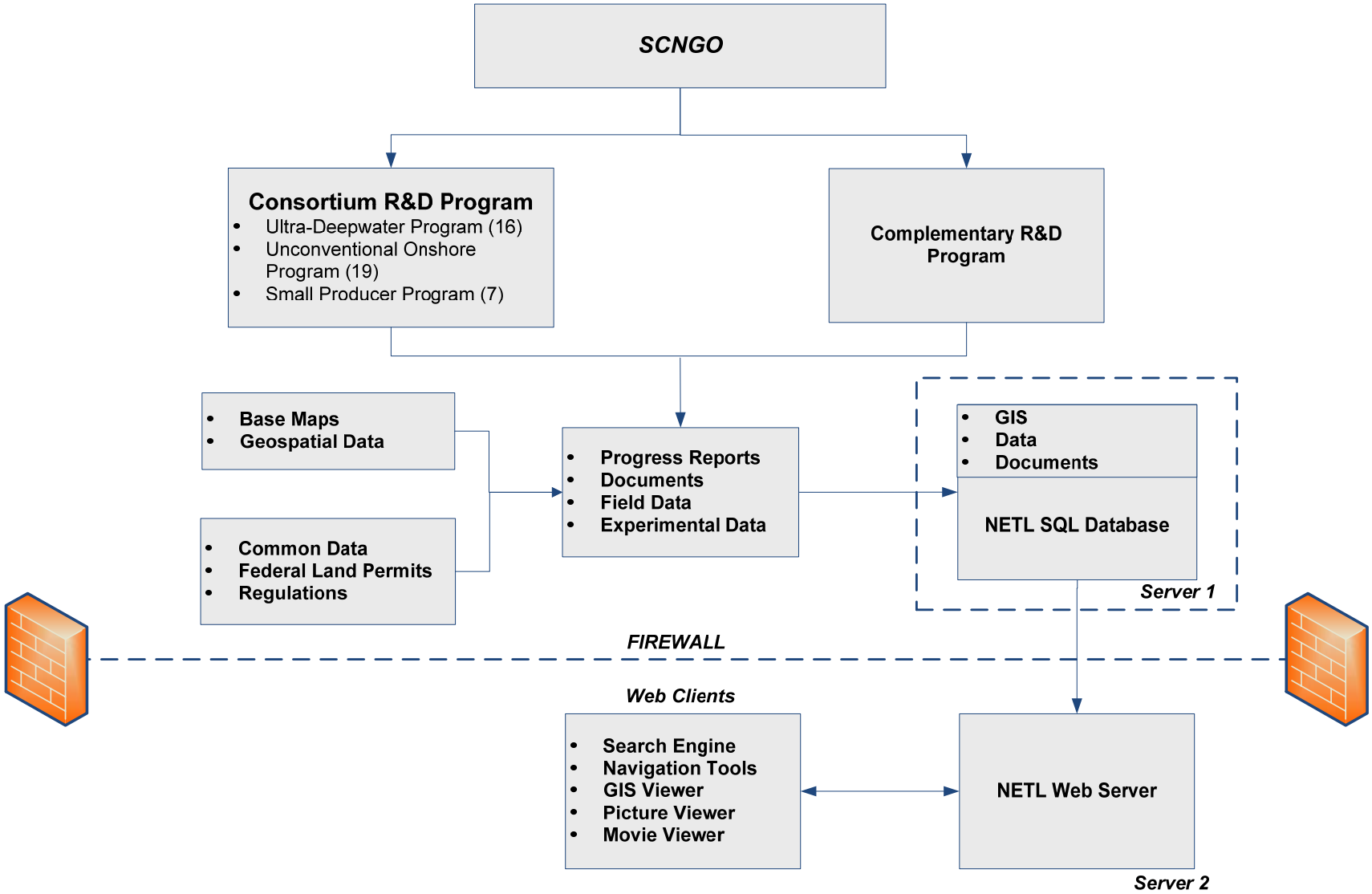
  Historic data is being gathered and cores retested to define the kerogen types and mineral components with modern microscopy
- Results will add to the understanding of gas generation and migration in the shale

Thomas Mroz

Resource Assessment Planned Procurements

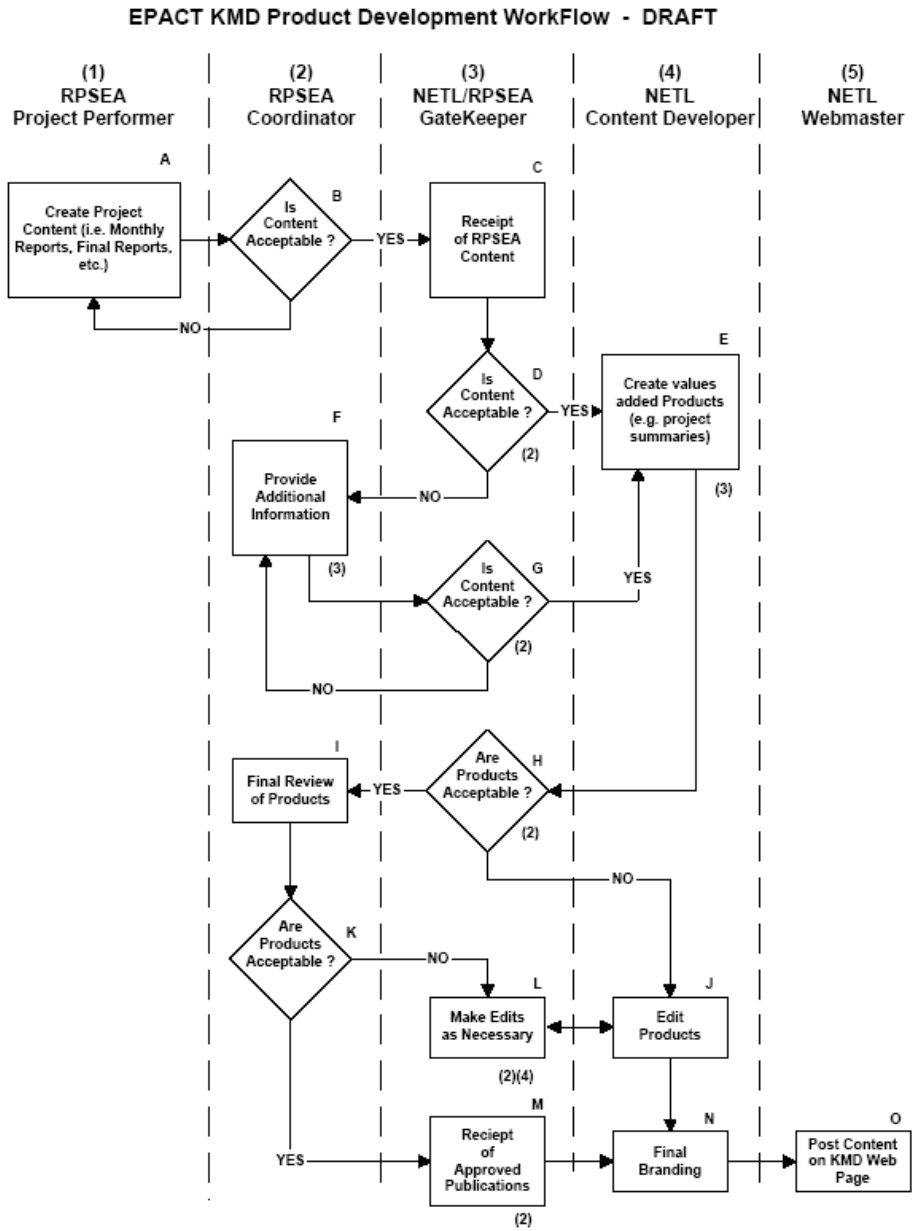
- **Microscopy enhancements including digital imaging software**
  - Acoustic microscope for shale porosity, permeability, and kerogen content
  - Digital upgrade of Etec SEM
  - Binocular high resolution UV microscope for analysis of cores and cuttings
  - Petrographic scope

KMD Concept


SCNGO
Consortium R&D Program
• Ultra-Deepwater Program (16)
• Unconventional Onshore Program (19)
• Small Producer Program (7)
Complementary R&D Program
• Base Maps
• Geospatial Data
• Common Data
• Federal Land Permits
• Regulations
• Progress Reports
• Documents
• Field Data
• Experimental Data
• GIS
• Data
• Documents
NETL SQL Database
Server 1
FIREWALL
Web Clients
• Search Engine
• Navigation Tools
• GIS Viewer
• Picture Viewer
• Movie Viewer
NETL Web Server
Server 2

EPAct KMD Workflow Diagram

- **Web site portal within NETL web site**
  - To provide a single locatio of the results and products of the Section 999 Prograr
  - Interactive problem solving features
    - Produced Water Management Information System (PWMIS)
    - SElf-Teaching Expert System (SETES) for gas production of fractured shale
- **FY09 will develop a work flow system with Consortium**
  - Includes reports, data, project status



Resource Assessment FY09 Plans

- Integrate the NETL oil shale and tar sand database and create links to other databases
- Prepare an annual report on gas and oil resource assessment for the Appalachian Basin
- Prepare a technical report on the integration of the Marcellus shale characterization task and updated database
- Complete a working version of the KMD