Assisting Indian Tribes with Oil and Gas Resources

Daniel J. Soeder, Research Geologist
National Energy Technology Laboratory
U.S. Department of Energy, Office of Fossil Energy

- Part of the DOE National Laboratory system
- Five locations with 1,200 staff
- “Full-service” DOE National Laboratory
- Research from fundamental science through technology demonstration
- Extramural research program with complimentary internal R&D
- Unique industry, academic and government collaborations
- The Nation’s only National Laboratory with a fossil energy focus
- The only government-owned, government-operated DOE National Laboratory
Why care about shale?

Source: U.S. Energy Information Administration reports and web pages.
Origins of Modern Shale Gas

- October 20, 1973 to Spring 1974: OPEC oil embargo against United States following the Yom Kippur War
  - Price of gasoline quadrupled ($0.40-$1.60)
  - Gasoline was in short supply, nearly rationed
- U.S. Department of Energy formed by the Carter Administration on August 4, 1977
- DOE funded natural gas R&D projects to increase domestic energy supplies:
  - Eastern gas shales
  - Western tight gas sands
  - Coalbed methane
  - Geopressed aquifers/ultra-deep gas
  - Methane hydrates
- Plus oil shale, tar sands, coal gasification, synfuels, biofuels, many others (origin of current “all of the above” energy strategy)
- DOE mission: offset imported oil by increasing domestic energy supply in an environmentally-responsible manner.
Shale Gas/Oil Resources

Shale has a long history of small-scale gas and oil production.

- Dunkirk Shale in Freedonia, NY (1821)
- Chagrin Shale along Lake Erie shoreline (late 1800s)
- Huron Shale (Big Sandy Field) in KY (early 1900s)

Engineering/economic challenges

- Oversimplified conceptual model: black shale + natural fractures = natural gas
- No one really understood why some shales produced and others did not
- Stimulation treatments were recognized as necessary, but often hit or miss
- Production was almost always small, with no effective way to recover economical amounts of gas
- Production of liquids was problematic and not well understood.

Higher prices on the high grade resource due to shortages make the low grade resource more cost competitive.

Technology advances make extraction of the lower grade resource cheaper and more cost-competitive.
Shale Geology from the 1980s

- Fine-grained, clastic mudrock, composed of clay, quartz, carbonate, organic matter, and other minerals.
  - Organic-rich shale is “black”
  - Organic lean shale is “gray”
  - Shale is commonly fissile

- **Shale porosity (φ) ~ 10%**
  - φ can be intergranular, intragranular, and intra-organic.
  - Small grains = small pores
  - Most φ in matrix; only ~1% φ in fractures
  - A component of gas is adsorbed onto organics

- **Shale matrix permeability (k) = μd to nd**
  - Permeability is typically a million times lower than conventional reservoirs
  - Gas flows from matrix to fractures, then to well

- **Dual porosity nature of shale is important**
  - Most of the φ (and gas) is in the matrix
  - Most of the k is in the fractures
  - High permeability flowpaths must access large rock volumes
New Technology for Shale Production

**Directional drilling**
- Invented in 1930s
- Industry overcame problems for use on deepwater platforms
  - Downhole hydraulic motors
  - Geosteering: MWD, LWD, inertial navigation
  - Up to 60 wells per tension-leg platform location.

**Hydraulic fracturing**
- Invented in 1947 by Floyd Farris, Stanolind Oil Co.
- Creates permeable pathways into a large volume of rock

**Shale development**
- Barnett Shale: 1997; George Mitchell applied horizontal drilling and staged hydraulic fracturing (5,000 ft; 10 stages)
- Fayetteville Shale: 2004; Southwestern Energy
- Haynesville Shale: 2004; Chesapeake Energy
- Bakken Shale tight oil play: 2005; EOG Resources, Nelson Farms 1-24H, Ross Field
- Marcellus Shale: 2007; Range Resources, Gulla #9
- Utica Shale: 2016; Eclipse Resources: Purple Hayes 1H: 18,544 foot lateral (3.5 mi) and 124 frac stages, probably a record.

Petroleum Geology Concepts

Conventional Reservoir: concentrated deposit of recoverable oil and/or gas.

NEED:
1. Source rock: 1-2% organics minimum
   a. Type I kerogen (lacustrine)
   b. Type II kerogen (marine)
   c. Type III kerogen (terrestrial)
2. Thermal maturity under anoxia
3. Reservoir rock
4. Trap and Seal
5. Migration pathway

If any one of these is missing, out of order, or timing is wrong = no production.

Unconventional Reservoir: production directly from/adjacent to a thermally-mature, high-organic content source rock.

- Reservoir rock, trap or seal NOT needed, engineered stimulation of reservoir IS needed.
- USGS calls this a “continuous resource” producible almost anywhere.
- Drilling location is based on infrastructure, not geologic structure.
Shale Gas Development

Dual Whiting triple drill rigs, Denver-Julesburg basin 2016

- Industrial-scale drilling operations on five-acre pads.
- Large drill rigs are required
  - Shale depths typically 5,000 to 15,000 ft
  - Lateral lengths typically 3,000 to 9,000 ft
- High-volume hydraulic fracturing is needed to recover economic amounts of gas or oil.
  - Large quantities of water, sand, and chemicals are used.
  - Flowback water recovered and recycled.
  - Residual liquid waste disposed of in UIC wells, solid waste in landfills.
- Potential environmental impacts
  - Air, water, landscapes, ecosystems

Bottomhole Assembly

Gas processing plant

Niobrara production, D-J Basin, photos by Dan Soeder
Shale Gas Development

Marcellus Shale hydraulic fracturing operation near Waynesburg, PA, 2011.

Photo by Dan Soeder
NETL Unconventional Oil & Gas (UOG)

Current Internal Research Areas

• Fugitive air emissions and greenhouse gases
  • Field data to support numerical modeling
  • Primarily focused on detecting methane leakage

• Water and geochemistry
  • Reservoir processes: subsurface geochemical reactions, microbial communities and biocides, sensors
  • Wellbore integrity, primarily focused on engineering properties of well cement
  • Surface responses: tools for groundwater monitoring, fate of black shale drill cuttings on surface

• Monitoring hydraulic fracture growth and ground motion
  • Passive seismic and microseismic monitoring to determine hydraulic fracture growth and stimulation effectiveness.

• Induced seismicity and geomechanics
  • Assessment of “slow slip” fault movements post-hydraulic fracturing
  • Potential to influence subsurface flow and large-scale fluid migration
NETL Unconventional Oil & Gas (UOG)

Selected, Relevant Extramural Research Projects

**Air**
- Advanced Analytical Methods for Air and Stray Gas Emissions and Produced Brine Characterization
- Leak Rate Estimation from NG Pipelines
- Time Series Modeling Investigation of Industry Changes to Emission Factors and Activity Data
- Life Cycle Analysis & Annual Natural Gas Sector Methane Emission Studies
- Tracking and Evaluation of Methane Abatement Technology and Best Management Practices across the Natural Gas Value Chain

**Water**
- Web-based Tool for Flowback and Produced Water Characterization, Treatment and Beneficial Use
- Novel Engineered Osmosis Technology: A Comprehensive Approach to the Treatment and Reuse of Produced Water and Drilling Wastewater
- Swellable Organosilica Materials to Clean Produced Water
- Development and Field Testing Novel Natural Gas Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid
- Development of Nanoparticle-Stabilized Foams to Improve Performance of Water-less Hydraulic Fracturing
- Water Handling and Enhanced Productivity from Gas Shales
- Development and Validation of an Acid Mine Drainage Treatment Process for Source Water
- Swellable Proppants for In-Situ Well Stimulation

**Wellbore Integrity**
- “Nanite” for Better Well-Bore Integrity and Zonal Isolation
- nXis Well Integrity Inspection in Unconventional Gas Wells
- Methods to Enhance Wellbore Cement Integrity with Microbially-Induced Calcite Precipitation
- Annular Isolation in Shale Gas Wells: Prevention and Remediation of Sustained Casing Pressure and other Isolation Breaches

**Field Laboratories**
- Marcellus Shale Energy and Environmental Laboratory (MSEEL)
- Hydraulic Fracturing Test Site (HFTS)
- Utica Shale Energy and Environmental Laboratory (USEEL)
Hydraulic Fracture Test Site:
Wolfcamp Formation
Gas Technology Institute

Lower 48 states shale plays

Utica Shale EEL
Ohio State Univ.

Marcellus Shale EEL
West Virginia Univ.

NETL-funded Unconventional Field Laboratories
Federal Multi-Agency Committee (MAC)

Established by Executive Order from President Obama in April 2012 directing DOE, DOI (mainly USGS) and EPA to jointly investigate hydraulic fracturing.

• Agency focus:
  • DOE: engineering risks
  • DOI: resource impacts
  • EPA: receptors/health impacts

• Research focus: UOG national plan, case studies (Marcellus, Barnett, Bakken)

• Plan completed and approved by EOP in 2013.
• Incorporates EPA drinking water assessment and DOE unconventional field laboratories
• HHS added for human health; NSF for coordination
• Congress has never funded.
Examples of Two Potential NETL Projects

• Assist Lakota people on the Rosebud Reservation in south central South Dakota to develop gas potential of the Niobrara Formation.
  • Gas shows in the Niobrara Formation were observed in 2012 when drilling low temperature geothermal wells at White River, SD
  • The Niobrara is very gas productive in Colorado and Wyoming; assessed as a prospective resource on Rosebud Reservation.
  • Original concept was to produce gas as revenue for the tribe, but it will have to be used locally (no transmission pipelines).
  • Preliminary assessment funded under AIHEC; tribe now awaiting DOI/BIA energy development grant for a well siting study, engineering design of a delivery/distribution system, and expanding the current environmental monitoring program.

• Assist MHA Nation on the Fort Berthold Reservation in western North Dakota to develop environmental monitoring programs for Bakken Shale production.
  • Fort Berthold straddles the Missouri River and is within the main Bakken Shale oil development area
  • As an oil play, Bakken wells are on closer spacing than typical shale gas wells, and are therefore more impactful to the landscape
  • Tribal members commonly express concerns about possible detrimental effects to air, groundwater and surface water.
  • Designing and implementing a comprehensive monitoring program will promote public confidence.
Rosebud Reservation Project

• Studies began in 2012 under a grant from American Indian Higher Education Consortium (AIHEC)
  • Sinte Gleska University, SD School of Mines and Technology, USDOE-NETL
  • Intent was to use research and evaluation of fossil energy resources on a reservation to provide STEM education to tribal students and suggest possible career pathways in oil and gas.

• Benefits
  • Tribe: resource information, introduce tribal students to oil and gas, develop community knowledge on fossil energy resource assessment and development, and provide access to potentially cheap energy.
  • DOE: Access to data on shale gas production and environmental monitoring.
  • SDSM&T: Real-world problem solving experience for graduate students.

• Approach was to analyze regional geology for prospects
  • USGS core library in Lakewood, Colorado, and regional rock outcrops
  • Fresh samples from South Dakota DENR drillhole near Presho, SD
  • Analyses: lithology, porosity, permeability, total organic carbon (TOC), thermal maturity, potential sweet spots
  • Geologic assessment and computer modeling to determine prospective resource.

Mikal Bordeaux (L) and Taylor Long Crow, students from Sinte Gleska University on a geological field trip to the southern Black Hills in 2014.

Photograph by Dan Soeder
The Niobrara is self-sourced
• Source beds have TOC contents between 2 to 8 wt%  
• Niobrara kerogen is dominantly Type II (sapropelic)  
• Thermally maturity varies significantly within and between the different basins.  
• Oil accumulations occur in oil window (Denver Basin).  
• Thermogenic gas occurs in deeper basins (Piceance).

Reservoirs are low-permeability chalks, shales, and sandstones.
• Biogenic methane occurs in shallow (< 3,000 ft.) chalk reservoirs on the east flank of the Western Interior Cretaceous Basin – this is expected at Rosebud  
• Shallow gas fields are found in northern Montana  
• Continuous or pervasive accumulations occur in thermally mature areas.

The Niobrara is a technology reservoir
• Horizontal drilling and multi-stage hydraulic fracturing required for production in deeper deposits.  
• Shallow deposits (eastern Colorado) have been produced by pinnate drilling using coiled tubing rigs.  
• The Niobrara petroleum system is present over most of the Rocky Mountain Region and is prospective in many areas.
Rosebud Reservation Project

Basic Niobrara geological, petrophysical and geochemical data needed to assess resource.
- Organic carbon content?
- Thermal maturity?
- Porosity and permeability?

Access to public cores at USGS core library in Denver and outcrops.
- Sampled for thin sections and rock eval
- Nothing very close to Rosebud Reservation
- Thin sections returned to USGS afterward

Depth, structure, and thickness modeled using Petrel software and public well logs
- Niobrara is above Dakota aquifer in SD
- Most deep water wells penetrate it; many report gas shows

Rosebud Reservation Project

Core B329, 1092 feet, Graves #31 Nemec, Stanley Co, SD

Core B329, 1128.5 feet, Graves #31 Nemec, Stanley Co, SD

Petrographic thin sections, white light, 70X magnification, blue epoxy in pores, red stain on calcite
Rosebud Reservation Project

Rock Eval and Organic Carbon Data
Rosebud Reservation Project

The Niobrara at Rosebud Reservation is too shallow to hydraulically fracture (<2500 ft.)

NETL-funded project in 2005 with ADT and Rosewood Resources in eastern Colorado:
• Drilled 25 wells in the Niobrara Formation
• Pinnate-style, horizontal wells
• Drilled using a high efficiency hybrid coiled tubing rig
• Made 300,000 feet of hole in 7 months
• Drilled and completed 3,000 ft. wells in 19 hours
• Colorado Oil & Gas Conservation Commission 2005 Operator of the Year Nominee
• World Oil Awards 2005 New Horizons Nominee
• Produced 1 TCF of shallow bypassed gas in the Niobrara
• Reduced the cost of drilling wells by 25-38%
• Reduced environmental impact
• Hybrid coiled tubing drill rigs now have a depth capability of 12,000 to 14,000 feet
Rosebud Reservation Project

Status:

• Rocks contain up to 6% total organic carbon, but thermal maturity is low; in “wet biogenic gas” window
  • Niobrara is only 1500 - 2000 ft. deep (450 - 600 m); drilling costs are cheaper
  • Too shallow to frac; pinnate drilling should be successful

• Resource is probably significant enough to produce and use locally, but NOT significant enough to justify the cost of a pipeline connection.
  • Current energy on reservation comes from outside; locally-produced gas could heat buildings and greenhouses, generate electricity, fuel motor vehicles, etc.
  • Opportunity for NETL to engage in utilization engineering research of stranded gas, which is an issue in many places without pipelines.

• Tribe applied for DOI/BIA energy development grant for engineering studies
  • A demonstration well design to assess delivery rates and estimated ultimate recovery
  • A surface distribution system design to deliver the gas is also required
  • Surface water monitoring was begun at Rosebud in 2016 by SGU students.

• The Rosebud Sioux tribal government supports this project for potential jobs, economic development, and affordable energy
  • Tribal government passed a resolution supporting this effort in 2016.
Fort Berthold Monitoring

Proposed NETL Assistance Project

- Project is in the planning stage – Soeder visited reservation in April 2016 for initial assessment.
- Tribal government and the Chairman of the MHA Nation have been supportive of environmental monitoring on Ft. Berthold.
- Chairman Fox asked Lisa Lone Fight to take the lead for the tribes
  - She is an enrolled member of the tribe and an Earth Sciences doctoral candidate at Montana State University.
  - She has a background in remote sensing and wants to apply it to monitoring.
  - We have talked and exchanged e-mails, but have not been able to define scope without guidance
- The project will have to be staffed locally to maintain sensors and collect periodic samples – this is outside NETL mission space.
- Soeder has discussed this with the USGS Water Science Center in Bismarck – they are interested but need a cooperative cost share agreement to do the work.
- Other options may be available.
- Because of time/space limits, monitoring sites will have to be selected strategically.

Photograph by Dan Soeder
The Bakken Shale
Bakken Development

From left:
Triple rig
Blow-out preventer (BOP)
Intermediate well casing
Bakken Development

From left:
Mud pump
Hydraulic foot to walk rig
Bakken Development

Dog house with driller and roughnecks
Drill rig controls
Bakken Development

From left:
Rig floor with roughnecks
Mud pit (tank)
Rig and pump jack
Bakken Development

Happy Campers
Fort Berthold Monitoring

Potential NETL Research with MHA Nation

- Air quality and GHG monitoring (Natalie Pekney area of interest).
- Remote sensing to assess “big picture” air emissions, surface water contamination and landscape degradation (Rick Hammack – Lisa Lone Fight area of interest).
- Water use optimization to determine most efficient (and least expensive) routes for moving water from river to well pads (Bob Dilmore area of interest).
- Groundwater monitoring wells near drill pads for periodic sampling and instrumentation.
  - The number of pads with monitoring wells is defined by the budget – how to optimize?
  - Microseismic to track hydraulic fractures
  - Tracer in frac fluid followed by possible drillback well to determine actual physical location.
- In-stream instrumentation to record continuous data on surface water quality with periodic sampling
  - This should be coordinated with USGS ND Water Science Center in Bismarck.
  - Number of instrumented sites defined by budget.
  - How to optimize location of instrumentation sites for maximum coverage?
Groundwater Risks

- Identified by National Ground Water Association in November 2014.
- Single biggest “contaminant” is methane gas, primarily caused by poor wellbore integrity – bad casing threads, poor cement job, improper curing, etc.
- Source and migration pathways of stray gas are notoriously hard to determine.
- Surface spills of drilling fluids, frac chemicals, and produced water are second largest concern: detection and fate/transport not well quantified.
- Risks change as practices evolve: i.e. water management
- Most risk comes from human error – when prescribed engineering practices are followed, risks are low.
Groundwater Risks

Marcellus Mapped Frac Treatments

Groundwater Risks

Marcellus horizontal well drilled below existing Upper Devonian production sands.

Pre-existing vertical Marcellus well between laterals.

PFC tracers in frac fluid to detect gas migration.

Groundwater Risks

- Goal: determine if gas from the Marcellus Shale migrates upward into the overlying Upper Devonian sandstone after the hydraulic fracture treatment
- Pressure sensors and post-frac monitoring for tracer.
- Models suggest 8+ years migration time for monitoring duration.

Stray Gas

Axetris Methane Sensor

- 0.1 nm narrow bandwidth diode laser beam is scanned across an absorption band of the target gas
- Instrument performs a high-resolution, near-infrared absorption measurement
- Detection method eliminates the need for a physical reference channel
- NETL lab tests indicate accuracy of 0.3 ppm on 10 second integration
- Target Gas: CH$_4$
- Cost: ~$9K
- Range: 10 ppm to LEL
- Accuracy: 0.3 ppm
Stray Gas

Issues for field use:
1) Avoiding condensation in the optical path from humid air out of a water well
2) Providing for adequate off-grid (unplugged) power supply to run laser continuously
3) Adding on-board data recording and/or telemetry; “vandal-resistance” (no laptop)
4) Programming for up to 30 days of all-weather unattended operations.

Solutions:
• Deep marine battery for power storage
• Solar panel to recharge system
• On-board processor and data storage
• Adequate power to run all systems continuously
• Membrane gas dryer to reduce humidity of incoming air sample
• Flowmeter, pump and pressure gages control gas throughput.
• Tubing (1/4 inch) collects gas from well headspace.
Fort Berthold Monitoring

Research Objectives

- **Mechanism of release**: How are contaminants entering the environment?
- **Fate and transport**: Where are the contaminants going and how fast are they getting there?
- **Probability of release**: What is the risk at different stages of drilling, stimulation/completion, and production?

Issues

- How do electronic instruments respond to these compounds?
- How frequently to sample? Before and after? Side by side?
- What are indicators of Bakken production? (Cl, Br, Ba, Sr, Ra, TDS)
- Where to place monitoring wells and stream sample locations?
- Can remote sensing be used to monitor more area?

Approach

- **Field Data** to establish baselines and impacts of processes
- **Laboratory Data** for simulations and confirmation of field data
- **Computational Tools** to characterize and predict system baselines and behavior
Monitoring Design

**Strategy**

- At least one year of baseline monitoring of groundwater and surface water surrounding a lease to determine flow pathways.
- Multi-level samplers will enable the measurement of discrete flow paths and provide a greater understanding of the site hydrogeology.
- Continuous groundwater monitoring during top-hole drilling through aquifer, and during hydraulic fracturing.
- Post-drilling water quality monitoring to detect acute or chronic water quality changes due to drilling.

**Surface Water (at key locations in affected watersheds):**
- Electronic sensors for pH, temperature, conductivity, DO, and turbidity.
- Periodic stream sampling for chemical analysis

**Groundwater (near selected well pads):**
- Upgradient reference well to base of deepest fresh water.
- Three or more downgradient wells to depth of deepest produced aquifer.
- Two downgradient wells equipped with multilevel samplers
- Upgradient well and one downgradient well equipped with electronic sensors.
- Methane monitoring in upgradient well.
- Periodic groundwater sampling for chemical analysis.

Reference herein to any specific commercial products, processes, or services by trade name, trademark, manufacturer, or otherwise is for descriptive purposes only, and does not constitute or imply an endorsement, recommendation, or favoring by the author or by any agency, entity or employee of the United States Government.
Fort Berthold Monitoring

Strategy:

• Electronic sensors for water level, pH, temperature, conductivity, DO, and turbidity in both surface water and groundwater.

• Periodic stream and well sampling for chemical analysis.
  • Inorganic indicator compounds for oil and gas include TDS, Ba, Sr, Li, Cl, Br, radionuclides (Ra), and possibly others as defined.
  • Because Bakken is an oil play, organics should also be monitored, including BTEX, DRO, and TOC

Configuration (per site):

• One up-gradient reference well, relatively deep (to base of deepest freshwater if possible), open hole completion, cored, equipped with a methane detector to measure headspace gases.

• Three down-gradient monitoring wells; depths of a few hundred feet; open hole completions, two equipped with multilevel samplers, the third equipped with continuous electronic monitoring instruments.

Schlumberger Westbay® downhole port (blue) and packer system (green) for isolating aquifer flow zones. (Photo by Dan Soeder)
QUESTIONS?

Daniel J. Soeder
U.S. Department of Energy
National Energy Technology Lab
Morgantown, WV 26507 USA
304-285-5258
Daniel.Soeder@netl.doe.gov