Shale Gas Risk Assessment and Evolving Technology

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Health Effects Institute Workshop
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In 2011, after the BP oil spill on the Macondo well, and in the wake of several contentious EPA stakeholder meetings on hydraulic fracturing, USDOE Secretary Steven Chu ordered DOE oil and gas research to focus on the environmental impacts of deepwater drilling and shale gas development.

In April 2012, President Obama ordered the EPA, DOE and the U.S. Department of the Interior (mainly the USGS) to cooperate on “fracking” research.

The three agencies signed an MOU, and assembled a study plan submitted to the White House in November 2012.

The Administration asked for funding in the FY14 budget.

DOE and EPA are moving forward using existing funds; USGS is awaiting funding.

Study plan available at http://unconventional.energy.gov/
Multi-Agency Environmental Assessment

Steering Committee of senior agency executives; chair alternates annually; Technical Committee of experts

- Assess the risks and receptors of hydraulic fracturing

- Unconventional Oil and Gas (UOG) national study plan; built on case studies (Marcellus, Barnett, Bakken)

- Focus on air, water, seismicity, and locations of future impact.

- Incorporates relevant current studies

- HHS and NAS have since been added to the MOU to address health issues and basic science.

- Six flagship projects developed in 2013 to interest Congress.

**ORD Approach for Shale Gas Development Risk**

**Goal: Deliver Risk Assessments for**
- Fugitive Air Emissions and GHG
- Produced Water Management
- Subsurface Migration of Gas and Fluids
- Induced Seismicity

**Research Plan Organization**
- U.S. Department of Energy
- Office of Fossil Energy
- National Energy Technology Laboratory
- NETL Office of Research & Development (ORD)

**Approach:**
- **Field Data** to establish baselines and impacts of development
- **Laboratory Data** for simulations, to understand processes and confirm field data
- **Computational Tools** to characterize and predict system baselines and behavior
Engineering Risk Assessment

- **Primarily developed for engineered geologic systems**
  - Underground nuclear waste isolation
  - CO$_2$ geologic storage
  - Oil and gas production: ultra deepwater and unconventional
  - Also known as a site performance assessment

- **Approach is probabilistic, focus is on the release of a hazardous material into the accessible environment.**
  - System divided into components
  - High fidelity, validated models are developed for each
  - Uncertainty reduction by focused data collection
  - Potential impacts of release generally not considered

- **Reduced order models (ROMs) are used to simplify predictions of high fidelity models for computation.**

- **ROMs are integrated into an Integrated Assessment Model (IAM) to predict total system performance and risk.**

- **Model is calibrated using field data and databases.**

- **IAM scenarios are run to test different system interactions.**

Reference DOE-NRAP study plan
October 20, 1973 to Spring 1974: OPEC oil embargo against United States
   – Price of gasoline quadrupled ($0.40-$1.60)
   – Gasoline was in short supply

U.S. Department of Energy formed by the Carter Administration on August 4, 1977

DOE funded R&D projects to increase domestic energy supplies:
   – Eastern Gas Shales
   – Western Tight Gas Sands
   – Coal Bed Methane
   – Geopressured Aquifers

Later projects (1990s)
   – Methane hydrates
   – Ultra deep gas

Objective: offset imported oil by increasing domestic energy production (in an environmentally-responsible manner).

Whence Shale Gas?

New Sources of Natural Gas

- Resources were known and in some cases substantial, but production was typically small.
  - Dunkirk Shale in NY (1821)
  - Huron Shale in KY (early 1900s)
  - Coal seam gas
  - Tight sands

- Engineering challenges
  - Natural fractures = natural gas (not always)
  - Two-phase flow is difficult in low permeability rocks
  - Formation contact limited with vertical wells and single hydraulic fractures

- Economic challenges
  - Not enough production to justify the cost of wells

Gas Shale Geology

- Fine-grained, clastic mudrock, composed of clay, quartz, carbonate, organic matter, and other minerals.
- Shale is organic-rich (black), or organic lean (gray), and commonly fissile.
- Shale porosity (φ) ~ 10%
- Shale permeability (k) μd to nd.
- Small grains = small pores; φ can be intergranular, intragranular, and intra-organic.
- Gas occurs in fractures, in pores and adsorbed or dissolved onto organic materials and clays.
- The gas potential of the Marcellus Shale is “surprising” – Soeder, 1988
Petroleum Geology

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

NEED:
1. Source rock: 1-2% organics (kerogen)
   a. Types I and II kerogen (petroleum + gas)
   b. Type III kerogen (coal + gas)
2. Thermal maturity
3. Reservoir rock
4. Trap and Seal
5. Migration pathway

If any one of these is missing, no production.

Shale gas is "unconventional": produced directly from thermally-mature high-organic content source rock. No reservoir, trap or seal needed.

USGS calls this a “continuous resource” producible anywhere
Why is the resource so large?
New Technology for Natural Gas Production

Developed for deepwater tension leg platforms; applied onshore.

**Directional drilling**
- Downhole hydraulic motors
- Geosteering:
  - Measurement while drilling
  - Inertial navigation
  - Telemetry: better electronics
- 5,000+ ft laterals

**Staged hydraulic fracturing**
- Light sand frac
- Slickwater frac
- Fast flowpaths in contact with large volume of rock

**Barnett Shale:** 1997; Mitchell Energy
**Fayetteville Shale:** 2004; Southwestern Energy
**Haynesville Shale:** 2004; Chesapeake Energy
**Marcellus Shale:** 2007; Range Resources: Gulla #9; IP 4.9 MMCFD
Large drill rigs are needed to reach depths of gas shales (typically 5,000 to 15,000 ft) and construct long laterals (typically 3,000 to 9,000 ft).

High volume hydraulic fracturing is needed to recover economic amounts of gas.

Large volumes of water, sand and chemicals are needed to support the operation.

Produced water is recycled; residual waste disposed of down UIC wells.
Shale Resources Worldwide

Legend
- Assessed basins with resource estimate
- Assessed basins without resource estimate
- Countries within scope of report
- Countries outside scope of report

Source: U.S. Energy Information Administration
Risks to Groundwater

- Identified by National Groundwater Association at a workshop in Pittsburgh, November 2014:
  - Single biggest “contaminant” is methane gas (even though there is no MCL). Explosive limits are 5% to 15%.
  - Single biggest cause is 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.
  - Risks come from human error – when prescribed engineering practices are followed, risks are low.

https://www.mathesongas.com/pdfs/products/Lower-%28LEL%29-%28UEL%29-Explosive-Limits-.pdf
## Groundwater Risk per Production Phase

<table>
<thead>
<tr>
<th>Production Activity</th>
<th>Potential GW Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial spud-in</td>
<td>air/fluid infiltration into aquifer</td>
</tr>
<tr>
<td>set surface casing; drill vertical well</td>
<td>well integrity: annular migration of fluids from open hole</td>
</tr>
<tr>
<td>set intermediate casing; drill lateral</td>
<td>low risk to groundwater</td>
</tr>
<tr>
<td>set production casing; complete well</td>
<td>frac chemicals on site; surface spills, potential leakage</td>
</tr>
<tr>
<td>hydraulic fracturing</td>
<td>abandoned wells, faults; frac chemicals on site; P-wave through aquifer</td>
</tr>
<tr>
<td>flowback and produced waters</td>
<td>frac chemicals and high TDS waters on site; surface spills, potential leakage</td>
</tr>
<tr>
<td>long-term gas production</td>
<td>well integrity: casing/cement deterioration; potential weathering of cuttings</td>
</tr>
</tbody>
</table>

Frac Fluid Chemicals

Average Hydraulic Fracturing Fluid Composition for US Shale Plays

Out of Zone Fractures

Marcellus Mapped Frac Treatments

Depth (ft)

Microseismic data, plotted against deepest freshwater aquifer on a county by county basis.

Frac stages (sorted on Perf Midpoint)

Environmental Risks to Water Resources

- **Surface spills and leaks**
  - Drilling fluids
  - Frac chemicals
  - Produced water

- **Direct aquifer impacts**
  - Drilling through aquifer
  - Pressure pulse from frac
  - Well integrity problems
  - Reservoir leakage

- **Land use impacts**
  - Headwater streams
  - Small watersheds
Does shale gas development cause stray gas migration in shallow aquifers?

Upward leakage from hydraulically-fractured target formation?
Wellbore integrity/direct leakage?
Mobilization of pre-existing methane in aquifer?
- Drilling through the aquifer
- Vibration caused by surface activity
- Compression from frac p-wave

Two questions:
What is the source of the methane?
How is the methane being mobilized?
Duke University study on 68 wells shows methane in groundwater in NE PA occurs in much higher concentrations near gas wells, and concluded it is related to wells. (Osborn, Stephen G., Avner Vengosh, Nathaniel R. Warner, and Robert B. Jackson, 2011, Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing: PNAS Early Edition Direct Submission article, available on-line only; Proceedings of the National Academy of Sciences, 5 p)


The proper question might be: how might drilling affect domestic water wells when methane is present in the aquifer?
June 6, 2012, Sardis, WV (near Clarksburg)
Drilled to 290 ft using water and air; bit got stuck around 150-170 ft. while withdrawing
The air compressor was left on as crews attempted to dislodge bit
Pressurized groundwater surged out of several old, unused wells nearby
Water Resources Research Trident

• Prong 1: Field Studies
  – Synoptic sampling and continuous monitoring
    • Downgradient wells to monitor contaminant migration
    • Upgradient well for reference and to monitor methane migration
    • Springs for discrete discharge sampling; stream for integrated samples
  – Schedule:
    • Baseline monitoring pre-drilling (monthly)
    • Frequent monitoring during drilling and hydraulic fracturing operations
    • Baseline monitoring for some time after well completion.

• Prong 2: Laboratory Analyses
  – Natural attenuation processes and rates
    • Drilling fluids
    • Frac chemicals
  – Instrumentation response and sensitivity thresholds

• Prong 3: Hydrologic Modeling
  – Gas/water displacement two-phase flow models
  – Reactive transport models
# Field Monitoring Research Issues

<table>
<thead>
<tr>
<th>Problem</th>
<th>Question</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do we drill a monitoring well? (not a</td>
<td>How do we avoid contaminating the aquifer with the very drilling chemicals we want to monitor?</td>
<td>Clean tubulars, no additives in cement, sample and analyze everything that goes into well, document all steps.</td>
</tr>
<tr>
<td>trivial question)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane in groundwater.</td>
<td>How do CH₄ concentrations vary in “undisturbed” groundwater? How is it mobilized by drilling?</td>
<td>Collect data to improve knowledge of CH₄ in aquifers; investigate potential gas migration mechanisms.</td>
</tr>
<tr>
<td>How much “baseline” data are needed to</td>
<td>How do dissolved chemical species vary temporally and spatially in “undisturbed” groundwater?</td>
<td>Collect data to improve knowledge of natural groundwater chemistry variability.</td>
</tr>
<tr>
<td>recognize an anomaly?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective use of geochemical tracers for</td>
<td>What are “undisturbed” groundwater values for common geochemical tracers?</td>
<td>Collect data to improve knowledge of variation in Sr, Ba, Br, Cl (water), and C, O, H isotopes (dissolved and gas-phase CH₄)</td>
</tr>
<tr>
<td>drilling/frac fluids.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soluble organic chemicals and polymers.</td>
<td>What are the background levels of these chemicals in groundwater? Do</td>
<td>Collect data on baseline levels of organic chemicals at site, and monitor for changes.</td>
</tr>
<tr>
<td></td>
<td>they change with drilling?</td>
<td></td>
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</tbody>
</table>
The Issue of Access

How can the scientific community obtain access to wells, cores, data, produced fluids and groundwater?

Access to sites, samples, and data for independent researchers has been difficult.

Industry scientists are not usually permitted to investigate issues that are unrelated to hydrocarbon production.

Public shale drill cores are 30 to 40 years old. New core is locked down by consortia and not generally available to outsiders.

Obtaining fluid samples is very hit or miss.

Most shales are deep – drilling is expensive.
Types of Accessible Gas Wells

Research Well
Non-commercial well drilled for research purposes. Driller is paid up-front for cost of well; does not need to produce it for revenue. Greatest freedom for researchers, but also the most expensive.

Transparent Well
Commercial well drilled on university or government land. Agency/university owns mineral rights; driller must produce well for revenue. Lease agreement may require the driller to allow various environmental monitoring programs to take place during well development.

Commercial Well
Investor-owned well drilled on a commercial lease. Driller must produce well for revenue to cover costs. Research access is at the discretion of the driller, and the landowner holding the lease.

Other options include piggy-back coring operations, formation water sampling during drilling, additional geophysics and logging, etc., usually for the cost of rig time.
Adventures in Groundwater Monitoring

- A stand-alone research well has not been funded.
- Several transparent wells have been planned:
  - Ohio State University in the Utica/Point Pleasant Shale.
    - Location: Southeastern Ohio on OSU land
    - Status: Awaiting drilling and land access agreements.
  - University of Tennessee in the Chattanooga Shale
    - Location: Knoxville (possibly in research forest)
    - Status: No industry interest in location, intense local opposition; project abandoned.
  - West Virginia University in the Marcellus Shale
    - Location: WVU Animal Husbandry Farm, Morgantown
    - Status: No pipelines nearby, uneconomical dry gas, project abandoned.
- Discussions by NETL-ORD with nearly a dozen companies so far have not resulted in access to commercial sites for groundwater studies.
Reasons Access has been Denied on Commercial Wells

- Potential new regulatory requirements
  - Success could require monitoring wells at every gas well pad.
  - Government agencies subject to FOIA requests may be forced to give up company “secrets.”
  - Research work by DOE is not regulatory, and sensitive information is protected from FOIA release.

- Negative data
  - If industry “does everything right” there will be nothing to measure, and we are wasting our time.
  - Making the measurement, even if nothing is found, reduces the level of uncertainty in the probabilistic risk assessment model.

- Already doing hydrologic monitoring
  - Industry is collecting pre-drilling water quality samples from domestic supply wells within a kilometer or more radius of the pad.
  - These samples are for exposure assessment and liability, not hydrology.
  - Domestic water supply wells are typically open hole completions and mix water from various levels in the aquifer, making them of little use for understanding aquifer behavior and groundwater flow paths.
  - Monitoring wells with multilevel samplers will better define aquifers.
Active and Recent Accessible Well Sites

DOE-NETL in the Marcellus Shale.
Location: Commercial field in Greene County, PA.
Status: Microseismic data collected during frac; ongoing collection of produced water and tracer sampling.
Problems: No groundwater component in study.

West Virginia University in the Marcellus Shale.
Location: Westover, WV on existing pad in industrial park.
Status: Agreements are in place with driller, university and DOE.
Problems: Hydrogeology is disturbed and very challenging for a groundwater study.

Pennsylvania DCNR in the Marcellus Shale.
Location: Moshannon State Forest adjacent to commercial lease.
Status: NETL moving forward to begin baseline monitoring.
Problems: Dry gas area; may not drill for several years if ever.
Greene County Well Site

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. No groundwater component.
Greene County Tracer Study

- Goal: determine if gas from the Marcellus Shale was migrating upward into the overlying Upper Devonian sandstone after the hydraulic fracture treatment
- Used PFC tracer and post-frac pressure and chemical monitoring; modeling suggests 8+ years migration time.
West Virginia University Study Site

- Marcellus Shale well on existing wellpad in Westover industrial park.
- First two wells on site were drilled and hydraulically fractured in 2012.
- Legacy environmental issues include an ammunition factory from WWII, and an adjacent Superfund site.
- Land access upgradient and downgradient is held by industrial park.
- Pittsburgh Coal was mined from this site sometime in the past.
- New gas wells will be installed in summer 2015, limiting baseline.
Moshannon State Forest, Tract 325, Pad B

- Exact location of monitoring wells will be defined by hydrogeology and flowpaths.
- One upgradient; at least 3 downgradient
- Continuous water quality and flow monitoring in stream.
- Samples from springs in area.
- GW wells planned spring 2015; gas wells maybe 2017, maybe never.
Multilevel sampler port with packer system for isolating aquifer flow zones.
## Target Analytes for Sampling and Chemistry

<table>
<thead>
<tr>
<th>Analytes</th>
<th>Method</th>
<th>Location</th>
<th>Team Members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major cations (Na, K, Mg, Ca)</td>
<td>ICP-OES</td>
<td>Pittsburgh Analytical Laboratory</td>
<td>William Garber, Tracy Bank (URS)</td>
</tr>
<tr>
<td>Metals and minor cations (Be, Sr, Ba, Cr, Mn, Fe, Al, As, Se)</td>
<td>ICP-OES</td>
<td>Pittsburgh Analytical Laboratory</td>
<td>William Garber, Tracy Bank (URS)</td>
</tr>
<tr>
<td>Anions (NO$_3^-$, SO$_4^{2-}$, Cl$^-$, Br$^-$)</td>
<td>IC</td>
<td>Pittsburgh Analytical Laboratory</td>
<td>Brian Kail (URS)</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>Alkalinity titration</td>
<td>Pittsburgh Analytical Laboratory</td>
<td>David Blaushild (URS)</td>
</tr>
<tr>
<td>Dissolved methane, BTEX, DRO, GRO, HEM</td>
<td>GC-MS</td>
<td>Chromatography Laboratory</td>
<td>Dirk Link (NETL), Brian Kail (URS)</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>TOC Analyzer</td>
<td>Environmental Geochemistry Laboratory</td>
<td>Vidhi Mishra (ORISE)</td>
</tr>
<tr>
<td>Strontium isotopes</td>
<td>Rapid analysis MC-ICPMS</td>
<td>NETL Multicollector/University of Pittsburgh</td>
<td>Thai Phan (ORISE)</td>
</tr>
<tr>
<td>Carbon and Hydrogen isotopes in dissolved and gaseous CH$_4$</td>
<td>IRMS</td>
<td>External subcontract (Isotech labs in the past)</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Field parameters to be measured: hydraulic head, pH, temperature, dissolved oxygen, specific conductance, oxidation-reduction potential, turbidity.
Moshannon Fieldwork

All photos by Dan Soeder, DOE
Complimentary Laboratory Studies

1. Sensor assessment
   – Can current water quality monitoring technology be used to detect hydraulic fracturing chemicals in surface water or groundwater?

2. Natural Attenuation
   – If chemicals associated with hydraulic fracturing were to spill or leak, what will be the fate and transport of such contaminants? Are NA processes and rates capable of keeping these chemicals out of the accessible environment?

3. Gas migration/Groundwater quality
   – Do drilling operations through aquifers affect shallow groundwater?
Gas Wells at Moshannon

- NETL-ORD research agreement is with state DCNR, although driller has agreed to collaborate.
- Lease is in place and pad has been designed (on paper) for gas wells.
- Driller needs $5.00/MCF gas price for these wells to be profitable.
- Current price $3.70/MCF; other wells in area are marginal, so company focus is on Greene County (SW PA).
- If they never drill: site will have exceptionally-well characterized groundwater above the Marcellus Shale.
- This could provide a reference for other sites where there might not be baseline or pre-drilling data.
- If operator abandons the lease, site could potentially be used for a research well.
- Other interested researchers could be invited to join in, turning this into a showcase monitoring and sampling site.
Questions?

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