Water Management in Unconventional Natural Gas Exploration & Production
An Important and Long-Term Challenge

May 2011
Introduction

• Massive expansion of shale gas development requires reliable water sources and effective water management

• This **multi-faceted challenge requires multi-faceted solutions**, and the purpose of this presentation is to explain and emphasize the importance of this fact

• My perspective
Presentation Outline

1) Summary of Shale Gas Resource
2) Horizontal Drilling and Hydraulic Fracturing
3) Water Management / Treatment
Growing Future Global Demand

- Global energy demand in 2030 will be about 35% higher than 2005, driven in large part by growth in power generation demand.

Source: ExxonMobil Energy Outlook
U.S. Reliance On Imports

Source: TrendMacro
It’s Not Going To Get Any Easier
(e.g., Chinese Oil Production and Consumption)

Source: EIA and BP Statistical Review
We Can All Agree

• Increase U.S. energy efficiency
• Reduce reliance on foreign sources
• Transition to renewable energy as quickly as possible
Where It Gets Sticky

• What do we do in the mean time while renewable energy development is a drop in the bucket compared to our total energy needs?
Blueprint for a Secure Energy Future

White House, March 30, 2011

• Three Point Plan
  – Develop and secure America’s energy supplies
  – Energy reduction
  – Innovate clean energy

“Natural gas and oil from shale formations...will play a critical role in domestic energy production in the coming decades.”
“We’ve discovered the equivalent of two Saudi Arabia’s in the last two years. The **greatest wealth transfer in human history** “$1B / day” takes place everyday and it doesn’t have to.”

- Aubrey McLindon, CEO of Chesapeake Energy

“One group says natural gas is the solution to America’s energy problems and another group says it’s our biggest environmental nightmare. **Their both right.**”

- Michael Brune, Executive Direction of the Sierra Club

“Given the global demand growth, concerns about nuclear power, constraints on carbon emissions, and current limitations of renewable energy, natural gas is the **fuel of no choice.**”

- Société Générale Bank
Shale Revolution Timeline
U.S. Shale Gas Production Has Increased Six-Fold Since 2006

Shale gas has grown to over 15% of U.S. gas production²

¹Source: EIA, Annual Energy Outlook 2011 Reference Case
²Source: EIA
Shale

- Sedimentary rock
- Consolidated clay-sized particles
- Concurrent deposition of organics (algae, plant matter, and animal matter)
- Laminated layers with limited horizontal and extremely limited vertical permeability (hence need for hydraulic fracturing)
U.S. Shale and Tight Gas Basins

Source: Energy Information Administration based on data from various published studies.
Natural Gas is Efficient and Clean Burning, and It’s OURS!

• \(~ \frac{1}{2} \text{CO}_2\) as coal
• Emits mostly \text{CO}_2\ and \text{H}_2\text{O}\ (\text{very small} \ \text{SO}_2\ and \ \text{NO}_x, \ \text{no ash})
• Central component of greenhouse gas strategies
• Extensive availability and transmission / distribution network
• Obvious best choice for leveling supply variability of renewable sources of wind and solar
• Massive U.S. Shale Gas Plays now available due to horizontal drilling and hydraulic fracturing
• Best available “bridge” fuel for future transition to renewable energy
Shale Gas is Global with Production and Reserves Both Concentrated in North America

Source: Wood Mackenzie
Shale Revolution

U.S. Dry Gas Supply – History and Projections

Shale gas in 2009 made up 14% of total U.S. natural gas supply. Production of shale gas is expected to continue to increase, and constitute 45% of U.S. total natural gas supply in 2035.

Source: EIA, 2011 Energy Outlook
Availability of Shale Gas Has Dramatically Changed U.S. Supply Projections

Source: Wood Mackenzie NAGS
Changing Supply Dynamics

*NE Shale vs. Traditional Appalachian*

Shale production in the Northeast grew 0.6 bcf/d in 6 months

Source: Bentek Energy, LLC
Domestic Shale Production Projections

Source: Wood Mackenzie (North America Gas Service)
Natural Gas Supply Trends

Source: Dominion Transmission Inc.
Marcellus Shale and Other Appalachian Formations

500 – 1,500 trillion cubic feet (tcf) in place (50 - 500 tcf recoverable) in the Marcellus.

First gas well in U.S. – 1821, Devonian Shale, Fredonia, NY.
A Trillion Cubic Feet is Enough Gas to:

- Heat 15 million homes for 1 year
- Generate 100 billion kilowatt-hours of electricity
- Fuel 12 million natural gas vehicles for one year
- Marcellus $\approx 50 - 500 \times$ above
Release of Natural Gas from Shale Rock

Source: BNK Petroleum
HORIZONTAL DRILLING AND HYDRAULIC FRACTURING
Horizontal Drilling

- Horizontal laterals: ~1.5 to 3 km long each
- Multiple stages hydraulically fractured stimulated
Horizontal Drilling

- Six to eight wells at a single site versus approximately 16 separate wells for typical vertical well spacing
- \(~1/10\) surface impact
- 2,000 – 6,000 feet of formation exposure per well versus only formation thickness (50 – 300 feet typical) for vertical wells
Barnett Shale: Intensive Drilling Activity 1997 - Present

Source: EIA
Environmental Concerns

• Air Emissions
• Water Supply / Water Handling / Water Disposal
• Surface Impact
  – Drilling Locations (Pit Construction; Chemical Storage; Erosion Control)
  – Infrastructure (Roads; Compressors; Pipelines; Water Treatment Facilities)
  – Truck Traffic and Road Damage
• Protecting Underground Water Resources
• Frac Fluid Disclosure

Source: Southwestern Energy
Marcellus Basin Surface Waters
The Shale Development Solution and Environmental Controversy

- Frac Water Volume: 2 to 6 M gallons
- Additional components include biocides, corrosion inhibitors, O2 scavengers, proppant, etc.
- 20 -30% frac “flowback” water recovery requires collection, handling, and disposal / treatment / reuse

Shale Gas and Water

- Source it
- Transport it
- Store it
- Treat it
- Re-use it
- Dispose of it
- Protect it
  - Surface Water
  - Ground Water
Key Water Management Concerns

- Water “wasting” and general water resource concern
- Surface water quality impacts
- Shallow groundwater quality impacts
- Long-term soil damage from salinity and sodicity (SAR)
- Transport – 1 MG = 200 trucks

**BOTTOM LINE:**

- Huge unconventional gas resources are driving development; and water solutions are key
- Water quality concerns leading to more treatment and reuse
- Solutions can be simple to very complex – *Reduce, Reuse, Recycle* are key goals
## Total Water Use – 4 Major Shale Plays

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<tr>
<th>Shale Gas Play</th>
<th>Public Supply</th>
<th>Industrial and Mining</th>
<th>Power Generation</th>
<th>Irrigation</th>
<th>Livestock</th>
<th>Shale Gas Use (Bbbl/yr)</th>
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<tbody>
<tr>
<td>Barnett Shale</td>
<td>82.70%</td>
<td>4.50%</td>
<td>3.70%</td>
<td>6.30%</td>
<td>2.30%</td>
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<td>Fayetteville Shale</td>
<td>2.30%</td>
<td>1.10%</td>
<td>33.30%</td>
<td>62.90%</td>
<td>0.30%</td>
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<td>Haynesville Shale</td>
<td>45.90%</td>
<td>27.20%</td>
<td>13.50%</td>
<td>8.50%</td>
<td>4.00%</td>
<td>0.80%</td>
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<tr>
<td>Marcellus Shale</td>
<td>11.97%</td>
<td>16.13%</td>
<td>71.70%</td>
<td>0.12%</td>
<td>0.01%</td>
<td>0.06%</td>
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</table>

*Source: Gas Technology Institute*
Shale Gas: Water Use Efficiency vs. Other Energy Sources

Shale gas is very efficient in terms of water use per unit of energy.

Source: GSI Environmental, Houston, Texas, 2010
Composition of a Fracturing Fluid

- Water and Sand: 99.5%
- Additives: 0.5%
  - Other: 0.049%
  - Surfactant: 0.085%
  - Friction Reducer: 0.088%
  - Acid: 0.123%
  - KCl: 0.06%
  - Agent: 0.056%
  - Scale Inhibitor: 0.043%
  - pH Adjusting Agent: 0.011%
  - Breaker: 0.01%
  - Crosslinker: 0.007%
  - Iron Control: 0.004%
  - Corrosion Inhibitor: 0.002%
  - Biocide: 0.001%

Reference: All Consulting 2009
Protection of Groundwater and Surface Water
This is a Critically Important Consideration

Source: BNK Petroleum
Oil & Gas Sites: Environmental Impacts in Regulatory Agency Records

• **KEY POINT:** Impacts to GW and SW by oil and gas wells are rare, with NO impacts recorded by shale gas wells
**KEY POINT:** Actual monitoring records show no change in surface water TDS before and after shale gas development.

*Source: EIA, GSI Environmental, Houston, Texas, 2010*
Shale Gas: Fast Rate of Water “Flowback”

- KEY POINT: After hydrofracturing, 20% - 40% of injected water “flows back” at initial rates of > 100K gals/day

Water Injection: Approx. 3 million gals in 4 to 10 days

Flowback Water: 30% return in 14 to 21 days

Produced Water: After flowback, typically 150 gals/day

Source: GSI Environmental, Houston, Texas, 2010
Total Dissolved Solids from the Produced Water Database in the United States

- Typical Produced Water TDS Levels – Selected Areas
  - Powder River CBM – 1200 mg/l
  - San Juan CBM – 4500 mg/l
  - Greater Green River – 8000 mg/l
  - Fayetteville Shale – 25,000 mg/l
  - Barnett Shale – 60,000 mg/l
  - Woodford Shale – 110,000 mg/l
  - Haynesville Shale – 120,000 mg/l
  - Permian Basin – 140,000 mg/l
  - Marcellus Shale – 180,000 mg/l

Source: USGS
Marcellus Flowback Characteristics

As frac water spends an increasing amount of time in the ground it transitions from fresh water to salty brine, dissolving salt compounds in the earth. Over time, volume decreases and TDS increases.

Source: Siemens AG 2009
## Current Produced Water Management by Shale Gas Basin

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<tr>
<th>Shale Gas Basin</th>
<th>Water Management Technology</th>
<th>Availability</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Barnett Shale</td>
<td>Class II injection wells</td>
<td>Commercial and non-commercial</td>
<td>Disposal into the Barnett and underlying Ellenberger Group</td>
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<td>Recycling</td>
<td>On-site treatment and recycling</td>
<td>For reuse in subsequent fracturing jobs</td>
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<tr>
<td>Fayetteville Shale</td>
<td>Class II injection wells</td>
<td>Non-commercial</td>
<td>Water is transported to two injection wells owned and operated by a single producing company</td>
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<td>Recycling</td>
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<td>For reuse in subsequent fracturing jobs</td>
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<td>Haynesville Shale</td>
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<tr>
<td>Marcellus Shale</td>
<td>Class II injection wells</td>
<td>Commercial and non-commercial</td>
<td>Limited use of Class II injection wells</td>
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<td>Treatment and discharge</td>
<td>Municipal waste water treatment facilities, commercial facilities reportedly contemplated</td>
<td>Primarily in Pennsylvania</td>
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<td>Recycling</td>
<td>On-site recycling</td>
<td>For reuse in subsequent fracturing jobs</td>
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<td>Woodford Shale</td>
<td>Class II injection wells</td>
<td>Commercial</td>
<td>Disposal into multiple confining formations</td>
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<td>Land Application</td>
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<td>Permit required through the Oklahoma Corporation Commission</td>
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<td>Recycling</td>
<td>Non-commercial</td>
<td>Water recycling and storage facilities at a central location</td>
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<td>Antrim Shale</td>
<td>Class II injection wells</td>
<td>Commercial and non-commercial</td>
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<td>New Albany Shale</td>
<td>Class II injection wells</td>
<td>Commercial and non-commercial</td>
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Shale Gas: Insufficient Injection Well Capacity in Northeast

**KEY POINT:** Very few Class II injection wells in Marcellus, requiring alternative methods of water disposal
# Treatment Technologies – Treatment Options

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Oil and Gas / Water Knowledge Convergence

COMMUNITY
- Energy Needs
- Environmental Concerns
- Limited Technical Expertise

OIL & GAS COMPANIES
- Exploration and Production Expertise
- Limited Water Expertise

ENVIRONMENTALLY SOUND ENERGY DEVELOPMENT

ENGINEERING AND SCIENCE COMMUNITY
- Water Expertise
- Limited Oil & Gas Exploration & Production Expertise

REGULATORS
- Environmental Management Responsibility
- New Challenges
- Stretched Resources
Questions and Answers

C. Hunter Nolen, P.E., BCEE
President, Industrial Services Group

CDM
1777 N.E. Loop 410, Suite 500
San Antonio, Texas 78217
210-826-3200 (office)
713-858-2372 (cell)
nolench@cdm.com (email)