Unconventional Gas Resources
Methane to Markets Partnership Expo
Beijing, China

Well Completion and Production Challenges
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James A. Slutz
Deputy Assistant Secretary
Office of Oil and Natural Gas
Office of Fossil Energy
U.S. Department of Energy
U.S. Natural Gas Supply Challenges

Unconventional Gas: Part of the Solution
• Tight Gas
• Gas Shales
• Coalbed Methane

Completion and Production Challenges

Summary

Questions
2007 U.S. Energy Use
Gas provides nearly one quarter of energy consumed

- Oil: 39%
- Gas: 23%
- Coal: 23%
- Nuclear: 8%
- Hydropower: 3%
- Biomass: 3%
- Renewables: 1%

AEO 2007
U.S. Demand for Gas Will Continue to Rise

- Gas 23% of Total
- Uncon. 37% of Gas
- 8.14 Tcf/year

- Gas 22% of Total
- Uncon. 37% of Gas
- 9.63 Tcf/year

AEO 2007
U.S. Natural Gas Supply Challenges

Supply Issues
- Imports rising (19% of consumption in 2006)\(^1\)
- Growing dependence on imported LNG
- Flat production despite record drilling
- Remaining resource increasingly costly to produce
- 88% of pipeline system installed prior to 1970’s\(^2\)

Environmental issues
- Competing land use/access restrictions
- Finding sites for new pipelines/facilities difficult
- More drilling required for unconventional sources (coalbed methane, shale gas, etc.) = more impact

1. DOE / EIA 2007; 2. NPC 2003
Vast Domestic Resource Available
More Difficult and Costly to Produce

- **100s Tcf in-place: Ultra-Deep Gas**
  - Recoverable, but not economic

- **1000s Tcf in-place: Tight Gas Sands, Shales, CBM**
  - 2% recoverable now; how much higher?

- **100,000s Tcf in-place: Methane Hydrates**
  - Recoverability not established
Unconventional Gas Production and Recoverable Resource

Source = EIA, ARI

<table>
<thead>
<tr>
<th>Resource</th>
<th>Technically Recoverable (Tcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tight Gas</td>
<td>379</td>
</tr>
<tr>
<td>Gas Shales</td>
<td>128</td>
</tr>
<tr>
<td>Coalbed Methane</td>
<td>73</td>
</tr>
</tbody>
</table>

Total Production: 19.5 Tcf (2004)
Character of Unconventional Gas “Resource Plays” Shape Challenges

- **Tight Gas**
  - Low Permeability
  - Continuous Deposition
  - Both Traditional and Basin-Centered Settings

- **Coalbed Methane**
  - Self-Sourcing Reservoir
  - Gas Adsorbed in Coal
  - Usually Requires Dewatering to Lower Pressure

- **Gas Shales**
  - Self-Sourced Plus Traditional Porosity
  - Gas Adsorbed in Organic Matter
  - Natural Fractures Required

Source = ARI
Federally Funded R&D Targeting Unconventional Gas Challenges Has Helped Production Growth
Primary U.S. Tight Gas Sand Basins

- Appalachians
- Wind River
- Uinta
- Green River
- Piceance
- Anadarko
- San Juan
- Permian/Val Verde
- Ft Worth
- South Texas trend
- South Texas trend
Tight Gas Completion-Production Technology Advances

- Advanced geologic modeling and fracture stimulation analysis led to smaller spacing
  - Lenticular sands with little continuity
  - Shift from 320 acres per well to <20 acres
  - Increased recovery from <5% to >50%

- Advanced hydraulic fracture designs
  - Multizone completions (often 5-15 zones per well)
  - Ultimate recovery per well increased from 1.5 Bcf to 5-10 Bcf

- Faster staged fracturing and emphasis on efficiency have lowered costs
Lenticular Sands, Little Continuity
### Impact of Reduced Well Spacing in Rulison Field, Piceance Basin, CO

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Wells &amp; Spacing (acres/well)</th>
<th>Reserves/Well (Bcf)</th>
<th>Recovery (Bcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>2 at 320</td>
<td>2.1</td>
<td>4</td>
</tr>
<tr>
<td>1994</td>
<td>2 at 160</td>
<td>2.2</td>
<td>4</td>
</tr>
<tr>
<td>1995</td>
<td>4 at 80</td>
<td>1.9</td>
<td>8</td>
</tr>
<tr>
<td>1996-97</td>
<td>8 at 40</td>
<td>1.8</td>
<td>14</td>
</tr>
<tr>
<td>1997</td>
<td>4 at 20 (pilot)</td>
<td>1.7</td>
<td>7</td>
</tr>
<tr>
<td>1998-2000</td>
<td>12 at 20</td>
<td>1.7</td>
<td>20</td>
</tr>
<tr>
<td>2004</td>
<td>32 at 10</td>
<td>1.7</td>
<td>55</td>
</tr>
</tbody>
</table>
## Impact of Multizone Completions

Jonah Field, Green River Basin, WY

<table>
<thead>
<tr>
<th></th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Generation</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Generation</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt; Generation</th>
<th>4&lt;sup&gt;th&lt;/sup&gt; Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pay Selection</strong></td>
<td>Bottom 40%</td>
<td>Bottom 20-50%</td>
<td>50%</td>
<td>50-100%</td>
</tr>
<tr>
<td><strong>Frac Stages</strong></td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>Up to 10</td>
</tr>
<tr>
<td><strong>Frac Fluid</strong></td>
<td>Cross-linked gel</td>
<td>Nitrogen</td>
<td>Nitrogen/gel</td>
<td>Borate gel</td>
</tr>
<tr>
<td><strong>IP (MMcfd)</strong></td>
<td>1.4</td>
<td>1 to 4</td>
<td>3 to 5</td>
<td>5 to 15</td>
</tr>
<tr>
<td><strong>EUR (Bcf)</strong></td>
<td>1.5</td>
<td>2.0</td>
<td>3.0</td>
<td>5 to 10+</td>
</tr>
</tbody>
</table>
Objective

- Develop and test an advanced hydraulic fracture mapping system with improved instrumentation that combines seismic sensors and tiltmeters in one tool

Accomplishments

- Completed field test of combined geophone/tiltmeter
- Tested placement of geophone/tiltmeter tool in treatment well. Good data sets gathered and tool survived hydraulic frac treatment
- Performed long term test of geophone/tiltmeter tool in San Andreas Fault Observatory at Depth (SAFOD) well
- Technology commercialized (2007)

Benefits

- Single observation well required, reducing costs
- Extends the capability of the best technology for optimizing hydraulic fractures
**Accomplishments**

- Completed detailed formation-based assessments of the Greater Green River, Wind River, Deep Anadarko, and Uinta Basins
- Confirmed the USGS view that a very large in-place, unconventional gas resource remains in the ground
- Distributed over 5000 CD’s so far, which include archived maps, cross-sections, & well data

**Benefits**

- Provide industry with detailed, basin-wide reservoir information, to guide their exploration and development efforts
Primary U.S. Gas Shale Plays and Basins

- Appalachian
- Denver
- Anadarko
- San Juan
- Ft Worth
- Piceance
- Williston
- Uinta
- Illinois
- Michigan
- Paradox
- San Joaquin
- Santa Maria
- Bakken Shale
- Antrim Shale
- Ohio Shale
- New Albany Shale
- Barnett Shale
U.S. Gas Shale Production by Region

Source: DOE/EIA
Individual Character of Gas Shales Shape Production Challenges

- **Devonian Shale (OH)**
  - Most historical production from Big Sandy field in KY and WV
  - Modest production began in 1920s and has continued to present
  - Wells produce 0.23 to 0.3 Bcf over 30 years

- **Antrim (MI)**
  - Must be dewatered like coal
  - Wells produce 0.4 to 0.8 Bcf at peak rates of 125-200 Mcfd and life of 20 years
  - >7800 wells drilled

- **New Albany (IL)**
  - Activity peaked in 1996 (~90 wells)
  - Must be dewatered

- **Lewis (NM & CO)**
  - Commonly commingled with deeper gas sands
  - Wells produce 2 Bcf at peak rates of 100-200 Mcfd and 6% decline rate

- **Fayetteville (AR)**
  - New play. Estimated EUR of 0.58 to 0.6 Bcf per well
  - Geologic equivalent of Barnett shale in Texas

- **Barnett**
  - Core Newark East Field produces >1 Bcfd. USGS estimates 26.7 Tcf gas-in-place.
  - Initial recovery rates of 8 to 15% are being boosted by new technology
DOE Gas Shales R&D Program Pioneered Technology Development in 70s and 80s

- **Horizontal Drilling for Gas Shales**
  - Drilled the first directional shale wells and the first air-drilled horizontal shale well

- **Foam Fracturing/CO₂ Fracturing**
  - Replaced open-hole explosive fracturing
  - Reduced volume of water used to transport proppant and lessened permeability damage

- **Formation Characterization and Evaluation**
  - Collected basic data on Eastern Gas Shales from more than 35 scientific test wells to define resource
  - Developed well logs and core analysis techniques designed specifically for shales
Barnett Shale Technology Advances

- Advanced Horizontal Drilling
  - Designed to intersect fractures
  - “3 times the well for 2 times the cost”

- Advanced Fracturing Techniques
  - Water fracs versus gel fracs
  - Must be contained to avoid water from underlying aquifer

- Advanced 3-D Seismic
  - Identifies where not to drill to avoid geologic features that might connect fractures to water

Photo: Devon Energy
Advanced Completion Technology
DOE Success: Coiled Tubing Drilling Demo
Gas Technology Institute

Objectives

- Demo first high efficiency hybrid CT rig built and operating in U.S.

Accomplishments

- Drilled 25 wells in the Niobrara
  - 300,000 feet of hole in 7 months
  - Drilled and completed 3,000’ wells in 19 hours

Benefits

- Made 1 Tcf of shallow bypassed tight gas in Niobrara economic
- Reduced the cost of drilling wells by 25-38%
- Reduced environmental impact

Photo courtesy Tom Gipson, ADT, LLC, Yuma, Colorado
Objective
- Develop a modified coiled tubing rig capable of drilling side-track wells in less time and less cost than conventional drilling rigs.

Accomplishments
- Completed all testing and modifications to improve safety, efficiency, underbalanced tool deployment, and data acquisition capabilities.
- Now commercial in Barnett Shale.

Benefits
- Advancements include: fatigue sensor; better hydraulic / control system, safer, smaller.
- Will accelerate and enhance development of the Barnett Shale gas resource, commercializing as much as 45 TCF of unconventional gas in this region.
U.S. Coalbed Methane Basins
### Coalbed Methane Resource and Production

<table>
<thead>
<tr>
<th>Region</th>
<th>Resource (Tcf)</th>
<th>2004 Production (Bcf/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Juan Basin</td>
<td>84</td>
<td>958</td>
</tr>
<tr>
<td>Powder River Basin</td>
<td>39</td>
<td>320</td>
</tr>
<tr>
<td>Other Rocky Mt. Basins</td>
<td>439</td>
<td>174</td>
</tr>
<tr>
<td>Cherokee and Arkoma Basins</td>
<td>10</td>
<td>75</td>
</tr>
<tr>
<td>Black Warrior Basin</td>
<td>20</td>
<td>121</td>
</tr>
<tr>
<td>Illinois/Appalachian Basins</td>
<td>87</td>
<td>72</td>
</tr>
</tbody>
</table>
U.S. Coalbed Methane Production by Region

Source: DOE / EIA
Factors Controlling CBM Production

- Fracture permeability
- Development cost
- Gas migration
- Coal maturation
- Coal distribution
- Geologic structure
- CBM completion options
- Hydrostatic pressure
- Produced water management
- Impacts vary from basin to basin
Coalbed Methane Completion-Production Technology Advances

- **Multi-Seam Completion (MSC) Technology**
  - Allows gas from thin coal seams to be produced along with that from thicker ones
  - Successful MSC in the Powder River Basin (PRB) CBM play will increase economically recoverable resource by 20+ Tcf

- **Advanced Horizontal Drilling**
  - Improved directional control of horizontal drilling
  - Multilateral drilling to access multiple cleat systems

- **Enhanced CBM (ECBM) Recovery**
  - Injection of CO₂ or N₂
  - U.S. CO₂-ECBM/sequestration potential assessed at 90 Gt CO₂ and 150 Tcf incremental recovery

- **Advanced Water Management**
  - Downhole separation and disposal, low cost reverse osmosis, phytoremediation, advanced membrane treatment
Coalbed Methane Completion-Production Technology Advances
DOE Success: Membrane Filtration Technology for Treatment of Produced Water

Texas Engineering Experiment Station

Goal

• Develop portable reverse osmosis membrane filtration technology for produced water

Accomplishments

• The desalination technology has been commercialized through GeoPure Water Technologies.
• System will process 20 gallons per minute of feed water

Benefits

• Reduces disposal costs by 75%
• Provides fresh water for beneficial use
Recent DOE Coalbed Methane Publications

- Analysis of Produced Water Management Alternatives
- Basic Primer on Coalbed Methane
- Available from DOE via websites

www.fossil.energy.gov
www.netl.doe.gov
Unconventional Gas Growing in Importance to U.S.
- Large resource in multiple basins
- Technical challenges vary from basin to basin and resource to resource

New Approaches Call for Innovative Thinking
- Some solutions can be transferred from basin to basin, some need modification

Integration of Technologies Will be Key
- Engineers, geologists, land use specialists

Environmental Issues Demand Technology Solutions
- Opportunities for R&D collaboration with industry
- Prerequisite for resource access
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