The MARCELLUS SHALE Play in Pennsylvania

John A. Harper and Jaime Kostelnik
Pennsylvania Geological Survey
YOU’VE HEARD ABOUT THE INCREDIBLE PRODUCTION RATES FOR THE MARCELLUS SHALE, OR READ THE NEWS REPORTS

- Average initial 24-hr open flow rate of 1 million cubic feet of gas per day (MMcfgpd)
- Initial production rate averaging 4 to 5 MMcfgpd from five vertical wells
- 24-hour initial production rate for 10 wells averaged 7.3 MMcf equivalent of gas per day
- Average initial open flow of 13 vertical wells was 1.3 MMcfgpd
- Average initial potential rate of 4.3 MMcfgpd
WHAT DO ALL OF THESE HAVE IN COMMON?

- **Average initial 24-hr open flow rate** of 1 million cubic feet of gas per day (MMcfgpd)

- **Initial production rate** averaging 4 to 5 MMcfd from five vertical wells

- **24-hour initial production rate** for 10 wells averaged 7.3 MMcf equivalent of gas per day

- **Average initial open flow** of 13 vertical wells was 1.3 MMcfgpd

- **Average initial potential rate** of 4.3 MMcfgpd
THE MARCELLUS SHALE

Some basic geology . . .
EXTENT OF DEVONIAN SHALES IN THE APPALACHIAN BASIN

Based on Milici and Sweezey, 2006
THICKNESS AND EXTENT OF THE DEVONIAN SHALE INTERVAL IN THE NORTHERN APPALACHIAN BASIN

Milici and Swezey, 2006
RELATIONSHIP OF DEVONIAN TECTONICS AND SEDIMENTATION

Carter, 2007

Syn- to post-orogenic deposits

Pre-orogenic stable shelf deposits
MIDDLE DEVONIAN (385 MA)
PALEOGEOGRAPHY OF LAURENTIA

Modified from Blakey, 2009
DEVONIAN DEPOSITIONAL ENVIRONMENTS

Modified from Laughrey, 2009
THE CATSKILL CLASTIC WEDGE

Approximately 1,500 feet

Organic-rich black shale
Dark gray shale and siltstone
Marine limestone
Deeper water gray shale and siltstone
Shallow marine siltstone and shale
Shallow marine sandstone, siltstone, and shale
Continental and transitional sandstone, siltstone, and shale

Hypothetical time line

Modified from Harper, 1999
ISOPACH MAP OF THE HAMILTON GROUP IN PENNSYLVANIA

Modified from Piotrowski and Harper, 1979
Marcellus – lower portion of the Hamilton group with higher than normal gamma ray responses

Mahantango – post Marcellus interval containing significant siltstones and sandstones

Non-radioactive interval lacking significant siltstones and sandstones as the “Hamilton Group undivided”
MISSISSIPPIAN AND DEVONIAN CORRELATION ACROSS THE APPALACHIAN BASIN

Wickstrom and others, 2005
TYPICAL GEOPHYSICAL LOG SIGNATURES

Mahantango Formation
“Normal” shale

Marcellus Formation
“Radioactive” (organic-rich) shale

Onondaga Limestone

Needmore Shale

Oriskany Sandstone

Oatka Creek Member
Cherry Valley Limestone
Union Springs Member
EARLY HISTORY OF APPALACHIAN SHALE GAS

1821-1825

- William Hart dug – with pick and shovel – a 27-foot deep gas well in the village of Fredonia, Chautauqua County, New York

- Gas provided the light of “two good candles”

- By 1825, it supplied enough natural gas for lights in two stores, two shops, and a grist mill

- The pipeline to transport the gas was made from hollowed-out logs connected together with tar and rags

Commemorative plaque on glacial erratic
PEOPLE NOTICED GAS BUBBLING UP OUT OF CANADAWAY CREEK.

http://www.wnysafariclub.com/PicPage%20Canadaway.htm
EARLY HISTORY OF APPALACHIAN SHALE GAS
1850-1860

- In 1850, the well was deepened to 50 feet and produced enough gas to light 200 burners.

- Fredonia Gas Light Company, North America’s first gas company, was formed in 1858 – they drilled a second well to more than 200 feet.

- Shale gas wells were dug along Lake Erie shoreline from Buffalo, NY to Sandusky, OH. After Drake, wells were drilled.
Wells are 200 to 1000 feet deep and have small flows – measured in ounces of pressure – but they last for scores of years.
1930 - 1980

DEEP GAS DRILLING

MAIN TARGET – ORISKANY SANDSTONE

Numerous shows of gas noted
EASTERN GAS SHALES PROJECT (EGSP)
LATE 1970S – EARLY 1980S

A multistate program spanning the Appalachian, Michigan, and Illinois basins

GOALS:

- Determine the extent, thickness, structure and stratigraphy of all Devonian organic-rich shales
- Develop and implement drilling, stimulation and recovery technologies
- Generate numerous cross sections, maps, and technical reports related to the entire Middle and Upper Devonian sequence in western and north-central Pennsylvania
PRODUCING DEVONIAN SHALE GAS FIELDS PRIOR TO DISCOVERY OF THE MARCELLUS PLAY

Wickstrom and others, 2005
EGSP IDENTIFIED THREE MAJOR AND THREE MINOR BLACK SHALE FACIES IN PENNSYLVANIA

**Major:** Huron, Rhinestreet, and Marcellus

**Minor:** Pipe Creek, Middlesex, and Geneseo/Burket

Carter, 2007
NET FEET OF ORGANIC-RICH SHALE IN THE UPPER DEVONIAN OHIO SHALE IN PENNSYLVANIA

Modified from Harper and Abel, 1980
NET FEET OF ORGANIC-RICH SHALE IN THE UPPER DEVONIAN WEST FALLS FORMATION (RHINESTREET SHALE) IN PENNSYLVANIA

Modified from Piotrowski and Harper, 1979
NET FEET OF ORGANIC-RICH SHALE IN THE UPPER DEVONIAN IN PENNSYLVANIA

Modified from Piotrowski and Harper, 1979
NET FEET OF ORGANIC-RICH SHALE IN THE MIDDLE DEVONIAN HAMILTON GROUP (MARCELLUS FORMATION) IN PENNSYLVANIA

Modified from Piotrowski and Harper, 1979
“THREE BELT” DISTRIBUTION OF THICK ORGANIC-RICH SHALE IN PENNSYLVANIA

Modified from Piotrowski and Harper, 1979; and Harper and Abel, 1980
RESULTS OF EGSP

1. Devonian organic-rich shales could be important gas reservoirs in northwestern Pennsylvania where they were both thick and close to the surface and have excellent potential to fill the needs of users if better technology for inducing and enhancing fracture systems was developed.

2. The Marcellus Formation was considered to be much less attractive and would remain so until gas prices increased and technology advanced enough to make drilling and completion competitive with more conventional targets.
THE MODERN MARCELLUS SHALE PLAY
“SO,” YOU MIGHT ASK, “WHAT HAS CHANGED?”

1. A **mind shift** from viewing shales as a source rock and seal for oil and gas reservoirs to viewing shales as source, seal AND reservoir

2. Technological advances in drilling, especially horizontal drilling

3. Use of **massive amounts of water** in hydraulic fracturing

4. Natural gas demand coupled with **higher energy prices**

5. Wall Street’s **acceptance of unconventional plays** such as coal bed methane, tight gas sands, oil shales, and shale gas
SO, HOW DID THE PLAY HAPPEN?

1. The “new” Marcellus shale play began in 2004, after Range Resources drilled a well in 2003 to the Lower Silurian in Washington County, PA. The deep formations (such as the Oriskany Sandstone) did not look favorable, but the Marcellus shale had some promise. Range completed the well late in 2004 as a producing shale well and drilled some additional wells in the area. They experimented with drilling and hydraulic fracturing techniques borrowed and revised from those used on the Barnett Shale gas play in Texas. Range began producing Marcellus gas in 2005. Since then, the company has permitted more than 150 Marcellus wells in Washington County alone.
SO, HOW DID THE PLAY HAPPEN?

2. Other companies took note and started following suit, and the play began heating up. Soon, there was a loud buzz within the oil and gas industry . . .

3. In late 2007, Penn State put out numerous press releases highlighting the research on the Marcellus by Dr. Terry Engelder and SUNY Fredonia collaborator Dr. Gary Lash in which they state the play could produce 50 trillion cubic feet of gas . . .

4. This helped bring the mainstream media into the play, increasing the visibility (and hype) tremendously.
SO, HOW DID THE PLAY HAPPEN?

5. Leases, which for years had been a “standard” $25/acre for 5 years with a 12.5% royalty, began climbing, and eventually went “through the roof” – some reaching as high as $6,000/acre and 25% royalty – as companies with deep pockets began taking an interest in the Appalachian basin.

6. Ironically, many of these companies had chosen for decades to ignore the Appalachians as not worth the investment, so they had to scramble to pick up leases, buy out existing operators, and learn the geology and engineering characteristics of the rocks.
THE MARCELLUS PLAY

Economic Limits of Marcellus Production???
The Marcellus play area extends from New York through Pennsylvania into West Virginia – a slim area of eastern Ohio contains Marcellus at 50 feet or thicker. Marcellus does not appear to extend into Kentucky at all.

Total vertical depths (TVD) drilled in the play thus far range from ~ 1,500 feet near the Lake Erie shoreline to ~ 9,300 feet in Elk County, PA.

It is most definitely an unconventional reservoir.
CONVENTIONAL PETROLEUM SYSTEM

1. Source rock (organic-rich shale) – generation and expulsion
2. Migration – from source to reservoir
3. Reservoir rock (sandstone or limestone) – holds petroleum in internal pore space
4. Trap (e.g. unconformity or fault) – keeps petroleum in reservoir
5. Seal – impervious rock such as shale or non-porous limestone
6. Overburden – buries reservoir under thousands of feet of rock
Reservoirs are NOT holes in the ground (e.g. caves and caverns).

They are solid rock with seemingly insignificant pore spaces.
SANDSTONE: A TYPICAL RESERVOIR ROCK
HIGHLY MAGNIFIED THIN SECTION OF A PIECE OF POROUS SANDSTONE EMBEDDED IN BLUE EPOXY TO SHOW THE PORE SPACES
Source rock elements (organic compounds) remain in the shale.

Reservoir and seal are vastly different than those in conventional systems.

Porosity (total pore space) and permeability (interconnected pore space) are low.
TYPICAL ORGANIC-RICH SHALE
HIGHLY MAGNIFIED THIN SECTION OF A PIECE OF ORGANIC-RICH SHALE SHOWING EXTREMELY FINE GRAIN SIZE

ALGAL SPORES

0.2 mm
SCANNING ELECTRON MICROSCOPE (SEM) PHOTO OF THE MARCELLUS ORGANIC-RICH SHALE
Marcellus shale. – “. . . has produced considerable quantities of gas in western part of Ontario County, New York. Certain wells have had rather large open flows but decline in production is generally rapid although a very small production may be maintained for many years. Seems to be most productive where fracturing and brecciation have opened joint-plains in which gas can accumulate.”
NATURAL FRACTURES IN SHALE

Photo courtesy of Gary Lash
ORIENTATIONS OF FRACTURES IN FIVE EGSP CORES IN PA
TYPICAL MARCELLUS DRILLING SITE

http://www.chiefog.com/drilling_process.htm
MARCELLUS SHALE DRILLING AND COMPLETION

- Conductor casing
- Surface casing
- Production casing

MARCELLUS FORMATION

Modified from Wiley and others, 2004
VERTICAL VS. HORIZONTAL DRILLING

Modified from Harper, 2008
A TYPICAL MARCELLUS FRAC JOB
WATER AND SAND INJECTED INTO WELL UNDER HIGH PRESSURE

Water, with additives, under high pressure fractures the rock.

Sand is used as a propping agent to keep fractures open.

Modified from Durham, 2007.
Supposedly keeps hydraulically generated fractures from penetrating upward and downward into adjacent formations.
WAYS TO STIMULATE A MARCELLUS WELL

- Primary Direction of Natural Fracturing
- Vertical Well Stimulation
- Horizontal Well With Longitudinal Stimulation
- Horizontal Well With Transverse Stimulation
A typical Marcellus Frac job uses approximately 3.5 million gallons of water.
COMPARISONS OF MARCELLUS WITH OTHER SHALE PLAYS

http://geology.com/articles/marcellus-shale.shtml
HOW DOES THE MARCELLUS STACK UP AGAINST OTHER GAS SHALES IN THE U.S.?

U.S. SHALE BASINS

Modified from Groundwater Protection Council, 2009
### COMPARISONS OF DATA FOR THE MAJOR U.S. SHALE PLAYS

#### EXHIBIT 3. COMPARISON OF DATA FOR THE GAS SHALES IN THE UNITED STATES

<table>
<thead>
<tr>
<th></th>
<th>Barnett</th>
<th>Fayetteville</th>
<th>Haynesville</th>
<th>Marcellus</th>
<th>Woodford</th>
<th>Antrim</th>
<th>New Albany</th>
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<tbody>
<tr>
<td><strong>Estimated Basin Area,</strong> square miles</td>
<td>5,000</td>
<td>9,000</td>
<td>9,000</td>
<td>11,000</td>
<td>12,000</td>
<td>12,000</td>
<td>43,500</td>
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<tr>
<td><strong>Depth, ft</strong></td>
<td>6,500–8,500</td>
<td>1,000–7,000</td>
<td>10,500–13,500</td>
<td>4,000–8,500</td>
<td>6,000–11,000</td>
<td>600–2,200</td>
<td>500–2,000</td>
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<tr>
<td><strong>Net Thickness, ft</strong></td>
<td>100–600</td>
<td>20–200</td>
<td>200–300</td>
<td>50–200</td>
<td>120–220</td>
<td>70–12</td>
<td>50–100</td>
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<tr>
<td><strong>Depth to Base of</strong></td>
<td>~1200</td>
<td>~500</td>
<td>~400</td>
<td>~850</td>
<td>~400</td>
<td>~300</td>
<td>~400</td>
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<tr>
<td><strong>Treatable Water, ft</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Rock Column between</strong></td>
<td>5,300–7,300</td>
<td>500–6,500</td>
<td>10,100–13,100</td>
<td>2,125–7,650</td>
<td>5,600–10,600</td>
<td>300–1,900</td>
<td>100–1,600</td>
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<td><strong>Pay and Base of</strong></td>
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<td><strong>Treatable Water</strong></td>
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<td><strong>Total Organic Carbon,</strong></td>
<td>4.5</td>
<td>4.0–9.8</td>
<td>0.5–4.0</td>
<td>3–12</td>
<td>1–14</td>
<td>1–20</td>
<td>1–25</td>
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<tr>
<td><strong>%</strong></td>
<td>4.5</td>
<td>2.8</td>
<td>8.0</td>
<td>10</td>
<td>3.9</td>
<td>3.0</td>
<td>10–14</td>
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<td><strong>Gas Content, scf/ton</strong></td>
<td>300–350</td>
<td>60–220</td>
<td>100–330</td>
<td>60–100</td>
<td>200–300</td>
<td>40–100</td>
<td>40–80</td>
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<td><strong>Water Production,</strong></td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>5–500</td>
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<td><strong>Barrels water/day</strong></td>
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<td><strong>Well spacing, Acres</strong></td>
<td>60–160</td>
<td>80–160</td>
<td>40–560</td>
<td>40–160</td>
<td>640</td>
<td>40–160</td>
<td>80</td>
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<tr>
<td><strong>Original Gas-in-Place,</strong></td>
<td>327</td>
<td>52</td>
<td>717</td>
<td>52</td>
<td>76</td>
<td>160</td>
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<tr>
<td><strong>Tcf</strong></td>
<td>44</td>
<td>41.6</td>
<td>251</td>
<td>11.4</td>
<td>20</td>
<td>19.2</td>
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<tr>
<td><strong>Reserves, Tcf</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Est. Gas Production,</strong></td>
<td>338</td>
<td>530</td>
<td>625–1,800</td>
<td>415</td>
<td>125–200</td>
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<tr>
<td><strong>mcf/day/well</strong></td>
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Modified from Groundwater Protection Council, 2009
COMPARISONS OF FOUR MAJOR SHALE PLAYS

**Haynesville**
- IP: 10.0 Mmcf/d
- 1st year decline - 81%
- EUR: 6.5 Bcf
- Well costs: $7 M
- FC: $1.44/Mcf
- NYMEX required: $3.88/Mcf

**Marcellus**
- IP: 4.3 Mmcf/d
- 1st year decline - 75%
- EUR: 3.75 Bcf
- Well costs: $3.5 M
- FC: $1.12/Mcf
- NYMEX required: $2.69/Mcf

**Barnett**
- IP: 2.5 Mmcf/d
- 1st year decline - 70%
- EUR: 2.65 Bcf
- Well costs: $2.8 M
- FC: $1.39/Mcf
- NYMEX required: $4.98/Mcf

**Fayetteville**
- IP: 1.9 Mmcf/d
- 1st year decline - 68%
- EUR: 2.20 Bcf
- Well costs: $3 M
- FC: $1.64/Mcf
- NYMEX required: $5.12/Mcf

*Modified from Chesapeake Energy, 2008*
WHAT DOES IT TAKE TO DRILL AND COMPLETE A MARCELLUS WELL?

- Drilling and completion costs - $1.5 TO 3.5 million per well
- Drillbit finding and developing cost – $1.12 per Mcf
- Vertical depth – 5,000 to 8,000 feet
- Horizontal length – 4,000 feet average
- Well stimulation – 4-stage fracture
- Time to drill – 30 days
- Assumed risk factor – 75%
PRODUCTION AND ECONOMICS OF MARCELLUS WELLS

Gas in place in the shale:

- Approximately 70 to 150 billion cubic feet per square mile (Bcf/mi²)

Vertical wells:

- Expected production – from 150,000 cubic feet per day (150 Mcf/d) to 5 million cubic feet per day (5,000 Mcf/d)
- Recovery Factor: 8 – 15%

Horizontal wells:

- Expected production – from less than 400 Mcf/d to 24,500 Mcf/d
- Recovery Factor: 20 – 40%

Data from Laughrey, 2009
VERTICAL VS. HORIZONTAL WELL PRODUCTION

Reserves:
- Vertical: 0.3 - 0.5 Bcf
- Horizontal: 0.75 - 1.0 Bcf

Avg 1st month IP:
- Vertical: 75 Mcfgpd
- Horizontal: 400 Mcfgpd

Cost:
- Vertical: $0.4M
- Horizontal: $1.2M

Reserves/Production ratio:
- Vertical: 20/1
- Horizontal: 13/1

ATAX (Pv10):
- Vertical: $106,000
- Horizontal: $370,000

Production Rate (Mcfgpd) vs. Years
- Vertical well
- Horizontal well

80 acres

Modified from Billman, 2009
PROJECTED MARCELLUS DECLINE AND CUMULATIVE CURVES

4.3 Mmcf/gpd initial open flow

2.11 Bcf after 10 years

Modified from DeWitt, 2008
MARCELLUS SHALE GAS RATE OF RETURN

Graph showing the relationship between NYMEX Gas Price ($/Mcf) and Before Federal Income Tax Internal Rate of Return. The graph includes lines for 4.25 Bcf, 3.75 Bcf, and 3.25 Bcf with error bars. The graph also shows a 10% Internal Rate of Return line. Modified from DeWitt, 2008.
THE MARCELLUS PLAY IN PENNSYLVANIA
MARCELLUS PLAY DISCOVERY WELL

Range Resources
Renz Well

Original Target: Silurian, Lockport Dolomite

Drilling Completed: July 2003
Stimulated: October 2004
MARCELLUS VS. ALL PERMITS ISSUED*

*Does not include pluggings, canceled, or expired permits
HORIZONTAL VS. VERTICAL MARCELLUS WELL PERMITS (AS OF APRIL 1, 2010)

- Red dots: Vertical Well
- Green dots: Horizontal Well
WHAT ABOUT REPORTED PA PRODUCTION???

The Marcellus play is relatively new, so there is very little data other than company stock projections.

Fortunately, Pennsylvania has the first four years’ worth of production data from Marcellus wells – 2005 to 2008.

Unfortunately, Pennsylvania collects only annual production totals, and by state law has to keep by-well data confidential for 5 years.

Fortunately, we can report aggregate numbers, which allows us to perform rough statistical analyses.

But, only if it doesn’t give away too much information!!!
The following charts show the average daily production of Marcellus wells in PA.

They were determined by dividing the total annual production of each well by the number of days it was in production during the year, then taking the average of those calculations.

The “year in production” is the numerical year, rather than the calendar year. Wells that produced for the first time in 2008 are included with wells that produced for the first time in 2005, 2006, and 2007. Year 1 is represented by many wells, whereas there are relatively few wells that have a fourth year of production.

Although the dashed lines connecting the midpoints at the tops of each rectangle mimic true decline curves, they are completely artificial, an artifact of the distribution of data across the four years.
MARCELLUS PRODUCTION
AVERAGE OF ALL VERTICAL WELLS

AVERAGE DAILY PRODUCTION (in Mcf)

YEAR IN PRODUCTION

1  2  3  4
MARCELLUS PRODUCTION
AVERAGE OF ALL HORIZONTAL WELLS

AVERAGE DAILY PRODUCTION
(in Mcf)

YEAR IN PRODUCTION

1 2 3 4
MARCELLUS PRODUCTION
COMPARISON OF VERTICAL AND HORIZONTAL
WELLS
COMPARISONS OF AVERAGE DAILY PRODUCTIONS
(variable numbers of wells)

<table>
<thead>
<tr>
<th>Formation</th>
<th>Avg Daily Production (Mcfpd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mississippian</td>
<td>50.40</td>
</tr>
<tr>
<td>Upper Devonian</td>
<td>53.12</td>
</tr>
<tr>
<td>Marcellus</td>
<td>605.04</td>
</tr>
<tr>
<td>Oriskany</td>
<td>116.59</td>
</tr>
<tr>
<td>Medina</td>
<td>32.03</td>
</tr>
</tbody>
</table>
THE MAJOR PLAYERS IN PENNSYLVANIA

NUMBER OF MARCELLUS PERMITS

Anadarko Petroleum
EXCO North Coast Energy
CNX Gas
EOG Resources
Cabot Oil & Gas
East Resources
Fortuna Energy
Atlas Energy
Chesapeake Energy
Range Resources
RESOURCE ESTIMATES

US Geological Survey (Milici and Swezey, 2006) –

- 259 Tcf gas-in-place (GIP)
- 1,925 Bcf recoverable

Industry and academe –

- 500 to 5,000 Tcf in place
- 50 to 500 Tcf recoverable!

Rational optimism (Kuushkraa and Stevens, 2009) –

- 1,600 Tcf in place
- 100 – 200 Tcf recoverable

In the long run, it will depend on the price of gas at the well-head
RISKS AND CHALLENGES TO PENNSYLVANIA’S MARCELLUS PRODUCERS

- Topography – Pennsylvania’s steep slopes
- Population centers
- Effectiveness of completions
- Pipeline capacity, transportation bottlenecks, and aging infrastructure
- Well permitting and other oil and gas regulatory issues
- Water use and disposal issues
- Fragmented mineral rights ownership
- Gas leakage, groundwater contamination, and geohazards
# WATER NEEDS FOR DRILLING AND FRACING

<table>
<thead>
<tr>
<th>Shale Gas Play</th>
<th>Volume of Drilling Water per Well (gal)</th>
<th>Volume of Fracturing Water per Well (gal)</th>
<th>Total Volume of Water per Well (gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett Shale</td>
<td>400,000</td>
<td>2,300,000</td>
<td>2,700,000</td>
</tr>
<tr>
<td>Fayetteville Shale</td>
<td>60,000</td>
<td>2,900,000</td>
<td>3,060,000</td>
</tr>
<tr>
<td>Haynesville Shale</td>
<td>1,000,000</td>
<td>2,700,000</td>
<td>3,700,000</td>
</tr>
<tr>
<td>Marcellus Shale</td>
<td>80,000*</td>
<td>3,800,000</td>
<td>3,880,000</td>
</tr>
</tbody>
</table>

* Drilling performed with an air “mist” and/or water-based or oil-based muds for deep horizontal well completions.

Note: These volumes are approximate and may vary substantially between wells.

Data from Groundwater Protection Council, 2009
NEED TO ADDRESS HYDRAULIC FRACTURING, WATER USE, AND FLOWBACK WATER MANAGEMENT

HYDRAULIC FRACTURING

EPA will revisit hydraulic fracturing technology (2004 study found no problems)

WATER USE:

The average Marcellus well uses about 3.5 million gallons of water

FLOWBACK WATER MANAGEMENT:

Industry/academe working on research to provide treatment technologies – about 30-40% of original water returned during flowback

- Polymer gel treatment
- Wetland management – environmentally friendly
- Recycling – water/salt separation processes (“demineralization”) – solid waste and brine trucked to disposal sites
  - Lower transportation costs
  - Reduced environmental conflicts
  - Reduce risk of interruption to development schedule
WATER RESOURCE CONCERNS

🌟 Water supply

– Water management plans – permit application

– Water withdrawal approval – Susquehanna River Basin Commission, Delaware River Basin Commission

🌟 Waste water disposal

– Identify where water will be stored, treated and disposed of prior to drilling

– determining the proper methods for the safe disposal of the large quantities of potentially contaminated fluids recovered from the wells
WATER USE AND DISPOSAL ISSUES

3 to 5 million gallons of water per hydro-fracturing job + a variety of chemicals

Flowback is 1/2 to 1/3 of this volume in a short time!

Flowback fluids will include a variety of natural rock ingredients as well as water and additives

- **Brine** – ancient sea water containing concentrated salts
- **Metals** – toxic and non-toxic
- **Hydrocarbons** – natural gas and liquids
- "**Radioactive**" material – naturally occurring uranium and thorium ions locked in the organic matrix

These require off-site treatment
TYPES OF MATERIALS USED IN TYPICAL MARCELLUS HYDRAULIC FRACTURING JOBS

Water – forced into the rock under very high pressure
Quartz sand – props open the fractures
Hydrochloric or muriatic acid – dissolves carbonate material in the rock
Ammonium bisulfate – oxygen scavenger
Glutaraldehyde - biocide
Sodium chloride (salt) - breaker
N,n-dimethyl formamide – corrosion inhibitor
Petroleum distillate or diesel – reduces friction
Guar gum or hydroxyethyl cellulose - gel
2-hydroxy-1,2,3-propanetricaboxylic acid – iron control
Ethylene glycol or 2-Butoxyethanol – scale inhibitor
Fluorocarbons, napthalene, butanol, and formaldehyde have also been used
## SUMMARY OF FRACING SOLUTIONS

<table>
<thead>
<tr>
<th>Product Vendor</th>
<th>Application Sequence</th>
<th>Product Name</th>
<th>Hazardous Components (MSDS)</th>
<th>(From) Hazardous Ingredient Weight %</th>
<th>Pounds of Hazardous Ingredient / Pound Water</th>
<th>Gallons of Frac Solution per Stage</th>
<th>Concentration in Frac Solution (ppm)</th>
<th>EPA Risk Based Concentration Residential Tapwater (ppm)</th>
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</thead>
<tbody>
<tr>
<td>BJS</td>
<td>1</td>
<td>HCl</td>
<td>Hydrochloric Acid</td>
<td>8%</td>
<td>0.015834</td>
<td>2000</td>
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<td>C1-14</td>
<td>Propargyl Alcohol</td>
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<td>0.00034327</td>
<td>2000</td>
<td>0.23</td>
<td>18</td>
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<td>Methanol</td>
<td>98%</td>
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<td>3.11</td>
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<td>Ferrotron 300L</td>
<td>Citric Acid</td>
<td>70%</td>
<td>0.00356</td>
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<td>XLW-32</td>
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<td>176.79</td>
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<td>Boric Oxide</td>
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<td>42000</td>
<td>39.29</td>
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<td></td>
<td>Polyacrylamide</td>
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<td>356.24</td>
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<td>GBW-20C</td>
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<td>BF-7L</td>
<td>Potassium Carbonate</td>
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<td>GDW-15L</td>
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</tbody>
</table>
PA Geological Survey

- **Stewards of well data**
  - Wells Information System (WIS)
  - Pennsylvania Internet Record Imaging System (PA*IRIS)

- **Geochemical database**
  - Source rock data
  - Thermal maturity, quality and quantity of organic matter
  - Available online at http://www.dcnr.state.pa.us/topogeo/oilandgas/source.index.aspx
  - New data
LOCATIONS OF AVAILABLE DATA
REFERENCES

Billman, D. A., 2009, Geological overview of Appalachian shale plays (or . . . . Why here?, Why now?).  
http://www.landman.org/content/file/Billman%20Shale%20AAPL%20Presentation%202-4-09.pdf.


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REFERENCES (cont.)


