FRACKING THE MARCELLUS IN PENNSYLVANIA

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Topics

- Economic significance
- Geology of Marcellus
- Construction and fracking
- Environmental Problems
Marcellus wells in PA, 2007–12

Unconventional Well Drilling Permits

Permit Year
- 2012 (3078 through 12/1)
- 2011 (2913 permits)
- 2010 (3143 permits)
- 2009 (1972 permits)
- 2008 (567 permits)
- 2007 (134 permits)

Marcellus extent
(includes non-economic areas)

Based on Pennsylvania Department of Environmental Protection permit activity reports.

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www.marcellus.psu.edu
Oil and Gas in PA

- First gas production in PA – late 1800’s
- More than 300,000 wells drilled since.
- Many have unknown locations
- Many were not plugged properly, leak into near surface.
- Most are relatively shallow, tapping horizons in the upper Paleozoic; a few deeper fields.
- Deeper fields are structurally controlled, shallow fields largely stratigraphic traps.
- Old very shallow wells near Erie tap shale, but supply only 1–3 homes.
Oil and Gas in PA – Conventional
PA Production

Average monthly natural gas production
billion cubic feet per day

Source: U.S. Energy Information Administration based on Bentek Energy, LLC.
Note: Rest of Northeast includes KY, MD, NY, OH, TN, VA.
Pennsylvania Gas Production Data

Production 1990’s ~0.2 Tcf/yr Value ~$0.4 billion/yr
Production 2011 ~1.3 Tcf/yr Value ~$6.3 billion/yr

Marcellus Production 2012: 2 Tcf ~$10 billion/yr
Marcellus wells drilled 2007–12: 6200

In 2007, about 1% of US production
In 2011, about 5% of US production
Marcellus Gas “Reserves” (Tcf)

- Energy Information Admin.: 410 earlier, 141 later
- “Reserves in Place” 1500
- Engelder (2009) 489

- 70 to 700 years of production at present rate

- Reserves depend on economics, price, technology, geologic interpretation.
Natural gas prices 1990–2011
$/Mcf

Residential

Wellhead
Wet gas vs. Dry gas
Ethane, butane, propane,.....
Utica Shale – Another gas source
Stratigraphy in PA

Figure 2. Generalized stratigraphic column of rocks in southwestern Pennsylvania. Numbers indicate geologic units referred to in this article: 1, Pennsylvanian and Permian coal beds; 2, Pottsville Formation Salt sands; 3, Venango Group oil sands; 4, Huron Shale; 5, Rhinestreet Shale; 6, Marcellus Formation; 7, Oriskany Sandstone; 8, Lockport Dolomite; 9, Medina Group and equivalent Tuscarora Formation; 10, Utica Shale; 11, Gatesburg Formation sandstones; and 12, Poisson Sandstone.
W–E cross section of Marcellus

Generalized Geologic Cross Section Showing Marcellus Shale in Western Pennsylvania

Marcellus Shale
Older Sedimentary Rock Formations
Marcellus Shale
Mixed Sandstone, Siltstone
Younger Black Shales
Youngstown, OH
Erie, PA
Clearfield, PA

Sandstone

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<table>
<thead>
<tr>
<th>Stratigraphic Unit</th>
<th>Description</th>
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<tbody>
<tr>
<td>Onondaga Ls, Huntersville Chert, Needmore Shale</td>
<td></td>
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<tr>
<td>Oriskany Sandstone</td>
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<tr>
<td>Union Spring Shale</td>
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<tr>
<td>Purcell/Cherry Valley Ls.</td>
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<tr>
<td>Stafford Limestone</td>
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<tr>
<td>Skaneateles Shale</td>
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<td>Centerfield Limestone</td>
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<td>Ludlowville Shale</td>
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<td>Tichenor Limestone</td>
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<tr>
<td>Moscow Shale</td>
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<tr>
<td>Tully Limestone</td>
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<tr>
<td>Genesee/Burkett Shale</td>
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<tr>
<td>Harrell Shale</td>
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<td>Mahantango Formation</td>
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<tr>
<td>Marcellus Shale</td>
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</table>

After Lash, 2007
Horizontal Well – Note casing

Cross-Section of Typical Horizontal Marcellus Well

24" conductor casing (brown) is installed up to 50 feet deep and cemented (grey) to the surface.

20" casing is installed through the 24" casing and continuing up to 500 feet deep. This casing is cemented to surface to isolate and protect near-surface groundwater.

13 3/4" casing is installed through the 20" casing and continuing up to 1000 feet deep. This casing is also cemented to the surface to protect the groundwater aquifer from the gas well.

5 1/2" casing continues down and is turned laterally into the Marcellus formation at a depth of 5000 to 9000+ feet below the surface.

Kick off point for the bend from vertical to horizontal drilling.

Horizontal, “lateral” portion of well extends from 3,000 to over 10,000 feet within Marcellus formation.
Importance of joints
Regional Joint Direction

Figure 4. Rose plots showing the orientation of joints in the Dunkirk middle Huron interval of cores recovered during the ECSP (modified from Cliffs Minerals, 1982). Well designations are those of the ECSP. Wells with less than three joints are omitted. Well WV-4 is corrected for misalignment as indicated by induced fractures.
Production decrease after fracking

Well Performance Continues to Improve

Marcellus Zero Time Plot of Gas Only by Well Type – As of June 30, 2010

<table>
<thead>
<tr>
<th>Type Curve (BCFE)</th>
<th>Gas (BCF)</th>
<th>Liquids (MBBLS)</th>
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<tr>
<td>5.0</td>
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<tr>
<td>4.5</td>
<td>3.2</td>
<td>214</td>
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<tr>
<td>3.5</td>
<td>2.5</td>
<td>167</td>
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</tbody>
</table>

2009/2010 Long Laterals
2009 Short Laterals
2008 Avg.

Gross Well Head Gas MCFD vs. # of Days

2008 (15 wells)
2009 Short Laterals (30 wells)
2009/2010 Long Laterals (45 wells)
Type Curve (5.0 BCFE)
Type Curve (4.5 BCFE)
Depth of fractures below surface during Fracking

Marcellus Shale Mapped Fracture Treatments (TVD)

Fisher, 2010
Chemicals added during fracking

- Sand or ceramic pellets
- Hydrochloric acid
- Biocides
- Gelling agents
- Gel stabilizers
- Clay stabilizers
- Corrosion Inhibitors
- Cross Linkers
- Friction reducers
- Iron control
- pH adjuster
- Scale Inhibitor
- Surfactant
Environmental Problems

- Wellpad
- Traffic, roads
- Site contamination
- Additives
- Flowback
- Methane in shallow ground water
- Pipelines
- Global warming – Methane effects
Marcellus gas is a major energy and economic benefit to the region and nation.

Gas and liquids from the Utica and other horizons will also be important.

The geology of the gas is complicated.

Many environmental effects must be handled skillfully.