

# Shale Gas:

## Focus on the Marcellus Shale

By Lisa Sumi  
FOR THE OIL & GAS ACCOUNTABILITY PROJECT/  
EARTHWORKS, MAY 2008





OIL & GAS ACCOUNTABILITY PROJECT  
P.O. Box 1102 • Durango, CO 81302 • [www.ogap.org](http://www.ogap.org)

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June 2008

Dear Reader,

We are pleased to provide you with this timely report on potential oil and gas development in the Marcellus Shale formation in northeastern Pennsylvania and southeastern New York. Oil and gas leasing is taking this region by storm and we have been deluged with calls, emails and letters from residents seeking information. Requests range from what is the difference between deep and shallow gas drilling to how to negotiate mineral leases and surface use and damage agreements to how to organize to what kind of regulations and laws exist to protect water and air quality from oil and gas development.

We hope that this report will help address many questions about the Marcellus Shale. We also encourage readers to review our landmark publication, *Oil and Gas At Your Door? A Landowner's Guide to Oil and Gas Development*. The guidebook is available on-line at <http://www.earthworksaction.org/LOguidechapters.cfm>. We also suggest that residents of the region contact these area organizations for more information on getting organized and informed about the issues surrounding oil and gas development:

**Catskill Mountainkeeper**

P.O. Box 381 • Youngsville, NY 12791  
(845) 482-5400 • [info@catskillmountainkeeper.org](mailto:info@catskillmountainkeeper.org)  
<http://catskillmountainkeeper.org/>

**Damascus Citizens for Sustainability**

P.O. Box 147 • Milanville, PA 18443  
[DCS@mailhosts.net](mailto:DCS@mailhosts.net) • <http://www.damascuscitizens.org/>

OGAP, the Oil & Gas Accountability Project, was founded in 1999 to work with communities to prevent and reduce the impacts caused by oil and gas development. In 2005 we merged with EARTHWORKS, formerly the Mineral Policy Center. Together, we have 5,000 members and offices in Bozeman, MT Durango, CO and Washington, D.C.

We fulfill our mission by working with communities and grassroots groups to reform government policies, improve corporate practices, and influence investment decisions. We work to encourage conservation, recycling, responsible materials policies, fuel efficiency, and renewable energy sources. We expose the health, environmental, economic, social and cultural impacts of irresponsible mineral development through work informed by sound science.

To join us visit: [www.earthworksaction.org](http://www.earthworksaction.org)

I want to acknowledge and heartily thank Lisa Sumi for taking on this project and producing such a thorough, well written and useful report under a very tight deadline.

Sincerely,

Gwen Lachelt  
OGAP Director

**About the Author**

Lisa Sumi is an environmental consultant who works on the environmental and community health impacts of extractive industries such as hardrock mining, and oil and gas. She has served as Research Director of two non-profit organizations – the Oil and Gas Accountability Project (2004-2007), and the Environmental Mining Council of British Columbia (1998-2002). In both cases, the work included science, technology and policy analysis; and community education and outreach. Lisa Sumi holds a Master of Science Degree from the University of Toronto.

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## INTRODUCTION

Natural gas prices have steadily increased over the past few years. This has spurred interest in the development of “unconventional”<sup>1</sup> gas resources, such as gas shales.<sup>2</sup>

The U.S. Energy Information Administration projects that by 2030, half of the natural gas produced in the U.S. will be from unconventional sources.<sup>3</sup> In 2005, approximately 10 trillion cubic feet (TCF) of conventional gas was produced in the U.S., versus 8 TCF of unconventional gas.<sup>4</sup> Natural gas from shale accounted for about 6% of the gas produced in the U.S. (1.1 TCF).<sup>5</sup> The majority of U.S. gas shale production came from four basins:<sup>6</sup>

- San Juan Basin, New Mexico/Colorado - 55 million cubic feet per day (mmcf/d)
- Antrim Shale, Michigan - 384 mmcf/d
- Appalachian/Ohio shales - 438 mmcf/d
- Barnett Shale, Fort Worth Basin, Texas - 1,233 mmcf/d

Exploratory gas-shale drilling is occurring across the country. Some of the areas include: the Devonian shale in the Appalachian Basin; the Mowry shale in the Powder River Basin; the Mancos shale in the Uinta Basin; the Woodford shale in the Ardmore Basin; a Floyd/Neal shale play in the Black Warrior Basin; the Barnett shale in the Permian Basin; the New Albany shale in the Illinois Basin; and others.<sup>7</sup>

This report focuses on the **Marcellus shale**, located in the Appalachian region of the U.S. Interest and exploratory drilling in the Marcellus shale is on the rise. This report was created to highlight some of the potential issues that may be important to consider if full-scale development occurs in the Marcellus shale. The information is based on experiences in other gas shale regions where development is in more advanced stages. Readers should be cautioned, however, not to assume that what has occurred in any other gas shale basin will necessarily occur in the Marcellus shale. There can be significant differences from one gas shale basin to another; and even within the same gas shale formation.

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<sup>1</sup> **Conventional gas** reservoirs are areas where gas has been “trapped.” After natural gas is formed, the earth’s pressure often pushes the gas upward through tiny holes and fractures in rock until it reaches a layer of impermeable rock where the gas becomes trapped. This gas is relatively easy to extract, as it will naturally flow out of the reservoir when a well is drilled.

**Unconventional gas** occurs in formations where the permeability is so low that gas cannot easily flow (e.g., tight sands), or where the gas is tightly adsorbed (attached) to the rock (e.g., coalbed methane). Gas shales often include both scenarios - the fine-grained rock has low permeability; and, gas is adsorbed to clay particles.

<sup>2</sup> Warlick, D. November, 2006. “Gas shale and CBM development in North America.” *Oil and Gas Journal*. Volume 3 Issue 11.

[http://www.oqfi.com/display\\_article/276354/82/ARCHI/none/none/1/Gas-shale-and-CBM-development-in-North-America/](http://www.oqfi.com/display_article/276354/82/ARCHI/none/none/1/Gas-shale-and-CBM-development-in-North-America/)

<sup>3</sup> U.S. Energy Information Administration (EIA). Feb. 2007. *2007 Annual Energy Outlook with Projects to 2030*. p. 93.

[http://www.eia.doe.gov/oiaf/archive/aeo07/pdf/0383\(2007\).pdf](http://www.eia.doe.gov/oiaf/archive/aeo07/pdf/0383(2007).pdf)

<sup>4</sup> U.S. EIA. Feb. 2007. *2007 Annual Energy Outlook with Projects to 2030*. p. 93.

<sup>5</sup> EnerDynamics. September 18, 2007. “The Rise in Unconventional Gas.” *The Energy Insider*.

[http://www.enerdynamics.com/documents/Insider91807\\_000.pdf](http://www.enerdynamics.com/documents/Insider91807_000.pdf)

<sup>6</sup> Pickering Energy Partners, Inc. Oct. 2005. *The Barnett Shale -Visitors Guide to the*

*Hottest Gas Play in the US*. Appendix B – Comparison of Organic Shales in the U.S. p. 46.

<http://www.tudorpickering.com/pdfs/TheBarnettShaleReport.pdf>

<sup>7</sup> Brown, D. April, 2007. “If It’s Shale, It’s Probably in Play,” *Explorer*. American Association of Petroleum Geologists.

[http://www.aapg.org/explorer/2007/04apr/beyond\\_barnett.cfm](http://www.aapg.org/explorer/2007/04apr/beyond_barnett.cfm)

## 1 MARCELLUS SHALE

Shale is the common name for rock that was once layers of clay or mud. Due to geological circumstances, these layers were compressed into a fine-grained sedimentary rock.

### How did the gas get there?

Marcellus is a Devonian-era shale, which means it originated approximately 350 – 415 million years ago. During that time, a lot of algae and other organisms died and fell to the bottom of a sea that covered what is now the eastern half of the U.S. These organisms provided carbon, which has since been converted into hydrocarbons, such as methane gas and crude oil. Illinois' New Albany shale, Michigan's Antrim shale, and Appalachia's Marcellus shale all date from this period.<sup>8</sup>

### Producing gas from shales

In many organic shale reservoirs, the natural gas is stored as free gas in fractures, and as absorbed gas on kerogen and clay surfaces within the shale matrix.<sup>9</sup> All rocks have pore space that can hold water or gases. In shales, the grains fit together so tightly that there is little movement of water or gas through the rock. In order for gas to be released, especially in "commercial" quantities, the shale must either have natural fractures, or fractures must be created in the rock.<sup>10</sup> (See hydraulic fracturing, Section 1.7)

## 1.1 Location

The Marcellus shale spans a distance of approximately 600 miles,<sup>11</sup> running from the southern tier of New York, through the western portion of Pennsylvania into the eastern half of Ohio and through West Virginia.<sup>12</sup> (By comparison, the Barnett has a linear extent totaling about 120 miles.)<sup>13</sup> The areal extent of the Marcellus shale is about 54,000 square miles,<sup>14</sup> which is slightly larger than Florida. The shale is extremely variable in thickness, ranging from a few feet to more than 250 feet in thickness,<sup>15</sup> and generally becomes thicker to the east.<sup>16</sup>

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<sup>8</sup> Shute, T. December 18, 2007. "The Next Great Gas Play." <http://www.fool.com/investing/value/2007/12/18/the-next-great-gas-play.aspx>

<sup>9</sup> January 2006. Shale Gas. A Supplement to Oil and Gas Investor. p. 16. <http://www.oilandgasinvestor.com/pdf/ShaleGas.pdf>

<sup>10</sup> Frantz, J.H. and Jochen, V. Schlumberger. October, 2005. "Shale Gas - When your gas reservoir is unconventional so is our solution." White Paper. [http://www.slb.com/media/services/solutions/reservoir/shale\\_gas.pdf](http://www.slb.com/media/services/solutions/reservoir/shale_gas.pdf)

<sup>11</sup> Durham, L.S. March, 2008. "Appalachian Basin's Marcellus – the new target." *Explorer*. American Association of Petroleum Geologists. <http://www.aapg.org/explorer/2008/03mar/marcellus.cfm>

<sup>12</sup> Jan 2008. "Unconventional Natural Gas Reservoir In Pennsylvania Poised To Dramatically Increase US Production," *Science Daily*. <http://www.sciencedaily.com/releases/2008/01/080117094524.htm>

<sup>13</sup> Durham, L.S. March, 2008. "Appalachian Basin's Marcellus – the new target." *Explorer*. American Association of Petroleum Geologists. <http://www.aapg.org/explorer/2008/03mar/marcellus.cfm>

<sup>14</sup> Mayhood, K. March 11, 2008. "Low down, rich and stingy - Energy companies just figuring out how to coax natural gas from deepest Appalachian shale deposits." *The Columbus Dispatch*. [http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci\\_shale.ART\\_ART\\_03-11-08\\_B4\\_A99I7HO.html?print=yes&sid=101](http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci_shale.ART_ART_03-11-08_B4_A99I7HO.html?print=yes&sid=101)

<sup>15</sup> Hill, D.G., Lombardi, T.E. and Martin, J.P. 2004. "Fractured Shale Gas Potential in New York." *Northeastern Geology And Environmental Sciences*. Vol. 26; Part ½. pp. 57-78.

[http://www.pe.tamu.edu/wattenbarger/public\\_html/Selected\\_papers/-/Shale%20Gas/fractured%20shale%20gas%20potential%20in%20new%20york.pdf](http://www.pe.tamu.edu/wattenbarger/public_html/Selected_papers/-/Shale%20Gas/fractured%20shale%20gas%20potential%20in%20new%20york.pdf)

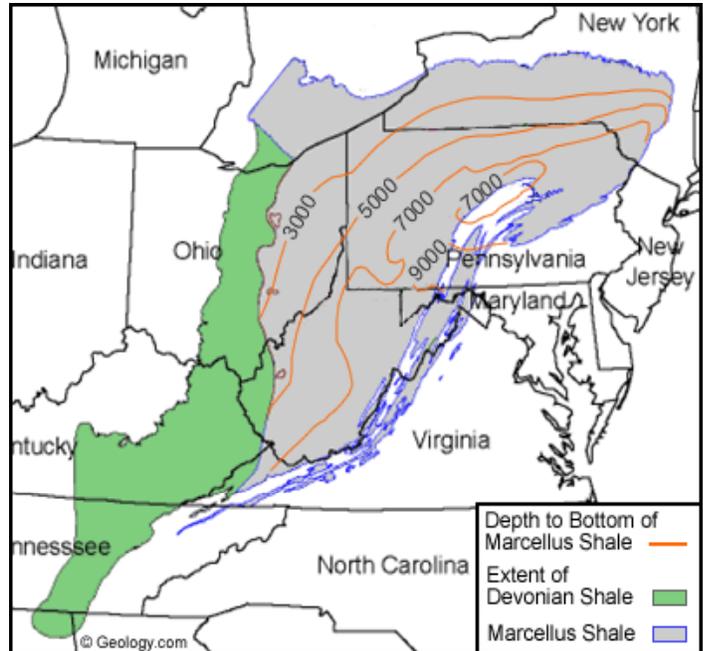
<sup>16</sup> Mayhood, K. March 11, 2008. "Low down, rich and stingy - Energy companies just figuring out how to coax natural gas from deepest Appalachian shale deposits." *The Columbus Dispatch*. [http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci\\_shale.ART\\_ART\\_03-11-08\\_B4\\_A99I7HO.html?print=yes&sid=101](http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci_shale.ART_ART_03-11-08_B4_A99I7HO.html?print=yes&sid=101)

## 1.2 Geology<sup>17</sup>

The Marcellus shale is said to have “favorable mineralogy” in that it is a lower-density rock with more porosity, which means it may be filled with more free gas.

Several characteristics of the Marcellus Shale change from east to west, and north to south:

- The west side has a higher organic content, but is shallower and thinner. This is where historical production has primarily taken place.
- The east side is deeper and thicker, with a higher quartz content (more brittle), but has a lower organic content. One question is whether multistage fractures in horizontal well bores can open the gas potential of the deeper, thicker eastern side.
- The northern part of the play is slightly geopressed.
- The southern part is underpressured.
- It is largely accepted that there is natural fracturing in the southern part, but some have questioned the extent of natural fracturing in the northern region; although others suggest that natural fracturing is present in both areas.



### Approximate Depth to the Base of the Marcellus Shale.

Map was prepared using the map by Robert Milici and Christopher Swezey above and plotting depth-to-Marcellus contours published by Wallace de Witt and others, 1993, United States Department of Energy Report: The Atlas of Major Appalachian Gas Plays.

Source: <http://geology.com/articles/marcellus-shale.shtml>

## 1.3 Depth of the Marcellus shale formation

Commercially productive gas shale reservoirs in the United States are found between 500 and 11,000 feet.<sup>18</sup> The more shallow shales include the Antrim (600-2,200 feet) and New Albany (500-2,000 feet); while deeper shales include the Barnett (6,500 – 8,500 feet) and Woodford (6,000-11,000 feet).<sup>19</sup>

The Marcellus formation is variable in depth, and in some areas of New York it outcrops (appears at the surface). The Marcellus shale was actually named for an outcrop found near the town of Marcellus, NY, during a geological survey in 1839.<sup>20</sup> The majority of the Marcellus shale, however, is more than a mile deep, and in some areas it extends 9,000 feet below the surface. (See map)

<sup>17</sup> February, 2008. "Operators Moving Toward Exploitation Phase In Marcellus Shale," *American Oil and Gas Reporter*.

[http://www.ptfc.org/aogr\\_columns/aogrcofeb08.htm](http://www.ptfc.org/aogr_columns/aogrcofeb08.htm)

<sup>18</sup> Schein, G. Dale Resources, LLC. Feb. 29, 2008. "Hydraulic Fracturing in Gas Shale Plays – Are they all the same?" Presented to the Fort Worth Business Press Barnett Shale Breakfast Symposium. Slide 5. <http://www.barnettshalenews.com/documents/GarySchein-FtWorthBusinessPress-ShaleCompletions-022908.pdf>

<sup>19</sup> January 2006. Shale Gas. A Supplement to Oil and Gas Investor. p. 17. <http://www.oilandgasinvestor.com/pdf/ShaleGas.pdf>

<sup>20</sup> Mayhoo, K. March 11, 2008. "Low down, rich and stingy - Energy companies just figuring out how to coax natural gas from deepest Appalachian shale deposits." *The Columbus Dispatch*. [http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci\\_shale.ART\\_ART\\_03-11-08\\_B4\\_A99I7HO.html?print=yes&sid=101](http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci_shale.ART_ART_03-11-08_B4_A99I7HO.html?print=yes&sid=101)

Until recently, the shale, which is at least twice as deep as most gas wells in Ohio, wasn't considered much of a resource because the gas is hard to reach.<sup>21</sup> The Marcellus Formation is still a very expensive target, with drilling costs approaching a million dollars for a traditional vertical well. (See Section 1.8 for more information on drilling costs)

## 1.4 Size of the resource

It has been conservatively estimated by Terry Engelder, a Pennsylvania State University geosciences professor and Gary Lash, professor of geosciences, SUNY Fredonia, that the entire Marcellus shale contains 168 trillion cubic feet (TCF) of **gas in place**. Engelder's more optimistic estimate is that it could contain 516 TCF.<sup>22</sup>

When so-called experts calculate the size of a gas reserve, they usually consider only 10 percent of gas in place as being **technically recoverable**.<sup>23</sup>

So, on the low size, the Marcellus shale is a potential resource of 16.8 TCF, and on the high side 50 TCF.

In 2006, the U.S. consumed more than 21 TCF of natural gas.<sup>24</sup> So, if the estimates by Engelder and Lash are correct, gas from the Marcellus shale could support this level of consumption for 1 to 2.4 years.

### DEFINITIONS

**gas in place:** the total amount of gas present in the rock.

**technically recoverable gas:** the percentage of that gas that can be recovered in the current economic climate using available technology.

**proved reserves:** the numbers a company uses when its evaluation is based on its drilling and production program, or history of production of gas.

## 1.5 Where is Marcellus shale drilling taking place?

Due to the variability in geology and depth of the resource, the economic and technical feasibility of extracting the shale gas will vary from region to region. For example, in West Virginia, there have sometimes been problems drilling through the Hamilton Group, which contains Marcellus and Rhinestreet shales. According to the Ohio Department of Natural Resources, "lost circulation due to the incompetent, fluid-sensitive shales is commonly reported. Also, the Hamilton is underpressured in this region, adding to drilling difficulties."<sup>25</sup>

According to Rodney Waller, senior vice president of Range Resources (one of the companies activity drilling the Marcellus shale), "There are wet gas areas, dry gas areas, more geologically complex areas. .

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<sup>21</sup> Mayhood, K. March 11, 2008. "Low down, rich and stingy - Energy companies just figuring out how to coax natural gas from deepest Appalachian shale deposits." *The Columbus Dispatch*.

[http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci\\_shale.ART\\_ART\\_03-11-08\\_B4\\_A9917HO.html?print=yes&sid=101](http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci_shale.ART_ART_03-11-08_B4_A9917HO.html?print=yes&sid=101)

<sup>22</sup> Jan 2008. "Unconventional Natural Gas Reservoir In Pennsylvania Poised To Dramatically Increase US Production," *Science Daily*.

<http://www.sciencedaily.com/releases/2008/01/080117094524.htm>

<sup>23</sup> Pletcher, J. May 19, 2008. "Drillers access mile-deep gas deposits in what may be new 'gold rush'." *Herald Standard*.

[http://www.heraldstandard.com/site/news.cfm?newsid=19696240&BRD=2280&PAG=461&dept\\_id=468387&rfi=6](http://www.heraldstandard.com/site/news.cfm?newsid=19696240&BRD=2280&PAG=461&dept_id=468387&rfi=6)

<sup>24</sup> Energy Information Administration. Basic Natural Gas Statistics. Table 1. Summary Statistics for Natural Gas in the U.S. 2002- 2006.

[http://www.eia.doe.gov/pub/oil\\_gas/natural\\_gas/data\\_publications/natural\\_gas\\_annual/current/pdf/table\\_001.pdf](http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_annual/current/pdf/table_001.pdf)

<sup>25</sup> Wickstrom, L.H., Slucher, E.R., Baranoski, M.T., and Mullett, D.J. 2008. *Geologic Assessment Of The Burger Power Plant And Surrounding Vicinity For Potential Injection Of Carbon Dioxide*. Ohio Department of Natural Resources. Open-File Report 2008-1. p. 26.

<http://www.dnr.state.oh.us/Portals/10/pdf/BurgerReport.pdf>

.There's a whole variety, and there are players who have drilled both horizontal and vertical wells in the Marcellus that are very good."<sup>26</sup>

Terry Engelder of Penn State predicts that drilling into Ohio's Marcellus shale will be more complex and costly than in New York, Pennsylvania and West Virginia. In those states, the gas is typically dry. In Ohio, the gas is more likely to be "wet," which means it's likely to be accompanied by petroleum or other liquids that have to be separated from the gas.<sup>27</sup> The infrastructure required to separate the liquids increases the upfront cost of the well.

The following summary is by no means complete. But it provides a sense that at the present time drilling in the Marcellus shale is spread throughout Pennsylvania, and, to a lesser extent, West Virginia and Ohio. Leasing is beginning to occur in New York.

### **Lycoming County, PA**

- Chief Oil and Gas LLC has drilled two wells in Mifflin Township and one in Watson Township — and, in late 2007 was preparing to drill a well in Penn Township. The company plans to drill three more wells early in 2008.<sup>28</sup>
- In April, 2008, Range Resources stated that it had drilled three wells in Lycoming County and was in the midst of its fourth.<sup>29</sup>

### **Fayette County, PA**

- Atlas Energy Resources has drilled 58 wells as of May, 2008. Atlas Energy Resources has about 250,000 acres under lease in southwestern Pennsylvania, which includes Fayette, Greene, Westmoreland and part of Washington counties.<sup>30</sup>

### **Washington County, PA**

- Range Resources has drilled five horizontal wells into the Marcellus shale.<sup>31</sup>

### **Susquehanna County, PA<sup>32</sup>**

- Turm Oil of Butler, recently drilled a well in Rush Township.<sup>33</sup>
- Cabot Oil has drilled a well in Dimock Township.<sup>34</sup>

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<sup>26</sup> Durham, L.S. March, 2008. "Appalachian Basin's Marcellus – the new target." *Explorer*. American Association of Petroleum Geologists. <http://www.aapg.org/explorer/2008/03mar/marcellus.cfm>

<sup>27</sup> Mayhood, K. March 11, 2008. "Low down, rich and stingy - Energy companies just figuring out how to coax natural gas from deepest Appalachian shale deposits." *The Columbus Dispatch*. [http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci\\_shale\\_ART\\_ART\\_03-11-08\\_B4\\_A9917HO.html?print=yes&sid=101](http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci_shale_ART_ART_03-11-08_B4_A9917HO.html?print=yes&sid=101)

<sup>28</sup> Thompson, D. Dec. 19, 2007. "County may sit on one natural gas mother lode," *Williamsport Sun Gazette*. [http://www.sungazette.com/page/content\\_detail/id/502945.html](http://www.sungazette.com/page/content_detail/id/502945.html)

<sup>29</sup> Mrozinski, J. April 23, 2008. "Not everyone will benefit from natural gas." *New Age Examiner*. [http://www.newage-examiner.com/site/news.cfm?newsid=19507278&BRD=2310&PAG=461&dept\\_id=480505&rft=6](http://www.newage-examiner.com/site/news.cfm?newsid=19507278&BRD=2310&PAG=461&dept_id=480505&rft=6)

<sup>30</sup> Pletcher, J. May 19, 2008. "Drillers access mile-deep gas deposits in what may be new 'gold rush'." *Herald Standard*. [http://www.heraldstandard.com/site/news.cfm?newsid=19696240&BRD=2280&PAG=461&dept\\_id=468387&rft=6](http://www.heraldstandard.com/site/news.cfm?newsid=19696240&BRD=2280&PAG=461&dept_id=468387&rft=6)

<sup>31</sup> Ross, C. Jan. 31, 2008. "Untapped gas reserve holds promise." *Indiana Gazette*. [http://online.indianagazette.com/index.php?option=com\\_content&task=view&id=19313&Itemid=64](http://online.indianagazette.com/index.php?option=com_content&task=view&id=19313&Itemid=64)

<sup>32</sup> Marritz, I. April 09, 2008. "Natural Gas Could Transform Sullivan County." WYNC. <http://www.wync.org/news/articles/96537>

<sup>33</sup> Wynne, P. Monday, May 19, 2008. "Gas-drilling misinformation causing unnecessary anxiety in Wayne County," *The Weekly Almanac*.

<http://weeklyalmanac.com/default.asp?sourceid=&smenu=1&twindow=&mad=&sdetail=8971&wpage=1&skkeyword=&sidate=&ccat=&ccatm=&restate=&restatus=&reoption=&retype=&repmin=&repmax=&rebed=&rebath=&subname=&pform=&sc=1020&hn=weeklyalmanac&he=.com>

<sup>34</sup> Wynne, P. Monday, May 19, 2008. "Gas-drilling misinformation causing unnecessary anxiety in Wayne County," *The Weekly Almanac*.

<http://weeklyalmanac.com/default.asp?sourceid=&smenu=1&twindow=&mad=&sdetail=8971&wpage=1&skkeyword=&sidate=&ccat=&ccatm>

- As of March, 2008, Southwestern Energy Company subsidiary SEPCO has drilled one exploratory well in Herrick Township. This is expected to be followed by two more exploratory wells in the County.<sup>35</sup>

#### Greene County, PA

- There have been number of wells that have shown Marcellus gas. The question is whether or not it can be made commercial.<sup>36</sup>

#### Clearfield County, PA

- Mid-East Gas Inc./M.M. & V Energy LLC. has partnered with Denver-based Rimrock Energy LLC, to begin deep well and horizontal drilling in this area. At the present time they are drilling test wells.<sup>37</sup>

#### Indiana County, PA

- Dominion Exploration & Production expects to drill 140 natural gas wells in Pennsylvania in 2008, and 25 to 30 of those will be in Indiana County. Penneco Oil Co. ordinarily drills five to 10 new wells a year in Indiana County, and that number could approach 15 in 2008.<sup>38</sup> It is not clear how many of the Dominion or Penneco wells will be drilled into the Marcellus shale formation.

#### Wayne County, PA

- Leases have been finalized in Wayne County, PA.<sup>39</sup>

#### Wyoming County, PA

- Leasing is occurring.<sup>40</sup>

#### West Virginia<sup>41</sup>

- PetroEdge is drilling a well in Wetzel County, and expects to drill in Marion and Ritchie counties.
- Cabot has drilled eight wells in southern West Virginia this year, with at least one in Jackson County.
- Dominion has been testing the Marcellus for three years now and expects to drill its first five to six producing wells this year, in the north-central part of the state.
- Other players in West Virginia include Equitable Resources Inc. and Chesapeake Energy Co.

#### Ohio

- Range Resources is evaluating a well in Jefferson County.<sup>42</sup> According to Range, Ohio is "more limited in potential than in Pennsylvania and West Virginia, but there are some areas, mostly along the Ohio River, that have better potential."<sup>43</sup>

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[=&restate=&restatus=&reoption=&retype=&repmin=&repmax=&rebed=&rebath=&subname=&pform=&sc=1020&hn=weeklyalmanac&he=.com](#)

<sup>35</sup> Keeler, D. March 13, 2008. "Herrick Township Well is First in PA for Texas Company," *Rocket Courier*. [http://74.95.82.236:591/rconline/FMPro?-find=&format=record\\_detail.html&-recid=12594476&-db=rconline.fp5](http://74.95.82.236:591/rconline/FMPro?-find=&format=record_detail.html&-recid=12594476&-db=rconline.fp5)

<sup>36</sup> Pletcher, J. May 19, 2008. "Drillers access mile-deep gas deposits in what may be new 'gold rush'." *Herald Standard*. [http://www.heraldstandard.com/site/news.cfm?newsid=19696240&BRD=2280&PAG=461&dept\\_id=468387&rfti=6](http://www.heraldstandard.com/site/news.cfm?newsid=19696240&BRD=2280&PAG=461&dept_id=468387&rfti=6)

<sup>37</sup> Lynn, W.B. April 16, 2008. "Drilling companies looking for natural gas in county," *The Progress*. <http://www.theprogressnews.com/default.asp?read=12052>

<sup>38</sup> Ross, C. Jan. 31, 2008. "Untapped gas reserve holds promise," *Indiana Gazette*. [http://online.indianagazette.com/index.php?option=com\\_content&task=view&id=19313&Itemid=64](http://online.indianagazette.com/index.php?option=com_content&task=view&id=19313&Itemid=64)

<sup>39</sup> Hust, D. January 18, 2008. "County is next frontier for gas exploration," *Sullivan County Democrat*. <http://www.sc-democrat.com/news/01January/18/news.htm>

<sup>40</sup> The Associated Press. February 3, 2008. Huge natural gas field mile below Appalachia tantalizes drillers. <http://www3.whdh.com/news/articles/national/BO72391/>

<sup>41</sup> Morris, J. March 23, 2008. "Getting ready for a gusher," *Charleston Gazette*. <http://wvgazette.com/News/Business/200803220388?page=2&build=cache>

- PC Exploration, based in Warrendale, PA, has two wells in Belmont County.<sup>44</sup>
- Exploration and drilling are occurring in Bradford County.<sup>45</sup>

### New York

- Petroedge Resources plans to drill two wildcat wells in Tioga County, NY, to evaluate gas in Marcellus shale.<sup>46</sup>
- Leasing is occurring in Sullivan County, NY.<sup>47</sup>

## 1.6 Vertical vs. horizontal drilling

The pore spaces in shales are typically not large enough for even tiny methane molecules to flow through easily. Consequently, gas production in commercial quantities requires fractures to provide permeability.

Shales may contain natural fractures that enable some movement of gas. These fractures are caused by pressure from the overlying rock and the natural movements of the earth's crust. Stress loads in the reservoir determine the geometry of the fractures.<sup>48</sup> (As mentioned in Section 1.2, it is likely that the southern extent of the Marcellus shale contains natural fractures, and it is quite possible that these fractures are present throughout most of the formation.)

Shale gas has long been produced from shales with natural fractures. Recently, however, there has been a lot more development of gas shales due to the use of techniques that create artificial fractures around well bores. This procedure is known as hydraulic fracturing. (See Section 1.7)

Horizontal wells are being used in several gas shale formations. This is because natural fractures (also known as "joints") in some shales, like the Marcellus, are vertical. When vertical wells are drilled, the borehole does not intersect many vertical fractures. Horizontal wells are drilled down vertically to the Marcellus and then horizontally through the shale formation itself. Thus, the wellbore in the shale is perpendicular to the most common fracture orientation, which allows it to intersect a much greater number of fractures.<sup>49</sup>

As far back as the 1980s, horizontal wells were contemplated and even drilled in Devonian shales like the Marcellus. While most of the wells were technical successes, they were ultimately considered failures because they did not produce at commercial rates. The primary reason they did not produce enough

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<sup>42</sup> Mayhood, K. March 11, 2008. "Low down, rich and stingy - Energy companies just figuring out how to coax natural gas from deepest Appalachian shale deposits." *The Columbus Dispatch*.

[http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci\\_shale.ART\\_ART\\_03-11-08\\_B4\\_A99I7HO.html?print=yes&sid=101](http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci_shale.ART_ART_03-11-08_B4_A99I7HO.html?print=yes&sid=101)

<sup>43</sup> Mayhood, K. March 11, 2008. "Low down, rich and stingy - Energy companies just figuring out how to coax natural gas from deepest Appalachian shale deposits." *The Columbus Dispatch*.

[http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci\\_shale.ART\\_ART\\_03-11-08\\_B4\\_A99I7HO.html?print=yes&sid=101](http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci_shale.ART_ART_03-11-08_B4_A99I7HO.html?print=yes&sid=101)

<sup>44</sup> Mayhood, K. March 11, 2008. "Low down, rich and stingy - Energy companies just figuring out how to coax natural gas from deepest Appalachian shale deposits." *The Columbus Dispatch*.

[http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci\\_shale.ART\\_ART\\_03-11-08\\_B4\\_A99I7HO.html?print=yes&sid=101](http://www.dispatch.com/live/content/science/stories/2008/03/11/Sci_shale.ART_ART_03-11-08_B4_A99I7HO.html?print=yes&sid=101)

<sup>45</sup> Feb. 6, 2008. "Oil and gas exploration needs review." *Daily and Sunday Review*.

[http://www.thedailyreview.com/site/news.cfm?dept\\_id=465724&PAG=461&BRD=2276&rft=9&newsid=19266888](http://www.thedailyreview.com/site/news.cfm?dept_id=465724&PAG=461&BRD=2276&rft=9&newsid=19266888)

<sup>46</sup> December 1 2007. Oil and Gas Investor This Week. <http://www.allbusiness.com/energy-utilities/oil-gas-industry-oil-processing/8923381-1.html>

<sup>47</sup> Hust, D. January 18, 2008. "County is next frontier for gas exploration," *Sullivan County Democrat*. <http://www.scdemocrat.com/news/01January/18/news.htm>

<sup>48</sup> Frantz, J.H. and Jochen, V. Schlumberger. October, 2005. "Shale Gas - When your gas reservoir is unconventional so is our solution." White Paper. [http://www.slb.com/media/services/solutions/reservoir/shale\\_gas.pdf](http://www.slb.com/media/services/solutions/reservoir/shale_gas.pdf)

<sup>49</sup> Shute, T. Dec. 18, 2007. "The Next Great Gas Play." <http://www.fool.com/investing/value/2007/12/18/the-next-great-gas-play.aspx>

gas is because most of the wells required some form of stimulation, which was too costly to undertake at the time.<sup>50</sup>

In the past few years, there has been an explosive growth of horizontal wells in shales (for example, in the Barnett shale). This is due to improvements in stimulation technologies. Multistage stimulation treatments are now performed on these wells to place hydraulic fractures around the borehole. The ability to economically stimulate the formation along the horizontal well bore has made these wells commercial successes.<sup>51</sup>

Wells that were previously drilled vertically to access Marcellus or other formations can be reused to drill horizontally through the Marcellus shale.<sup>52</sup>

It has been reported that Range Resources is likely to move to horizontal wells in the Marcellus formation, but the company is fully testing both vertical and horizontal wells before it makes a wholesale commitment. In 2007, Range was planning to drill 35 vertical and 15-20 horizontal wells in Washington County and two other main areas.<sup>53</sup>

Other companies are experimenting with horizontal wells. Cabot Oil and Gas has recently spudded its first horizontal Marcellus test in West Virginia.<sup>54</sup>

Not all companies are convinced that horizontal wells will be required to effectively drain gas from the Marcellus shale. For example, Atlas Energy recently announced that after reviewing the effective length of its hydraulic fractures, the company believes that it will be able to develop its southwestern Pennsylvania Marcellus leases using vertical wells.<sup>55</sup>

### 1.6.1 Cost of drilling

There have been various estimates and reports on the costs of drilling wells into the Marcellus shale:

**Terry Engelder (Penn State):** \$800,000 to drill a vertical well in the Marcellus, and \$3 million to drill a horizontal well.<sup>56</sup>

**Atlas Energy, Fayette County, PA:** Atlas is drilling both vertical and horizontal wells in the Marcellus shale. The company says it costs about \$1.3 million to drill a vertical well and that drilling a horizontal well could cost as much as \$4 million.<sup>57</sup>

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<sup>50</sup> Hill, D.G., Lombardi, T.E. and Martin, J.P. 2004. "Fractured Shale Gas Potential in New York." *Northeastern Geology And Environmental Sciences*. Vol. 26; Part 1/2. pp. 57-78.

[http://www.pe.tamu.edu/wattenbarger/public\\_html/Selected\\_papers/-Shale%20Gas/fractured%20shale%20gas%20potential%20in%20new%20york.pdf](http://www.pe.tamu.edu/wattenbarger/public_html/Selected_papers/-Shale%20Gas/fractured%20shale%20gas%20potential%20in%20new%20york.pdf)

<sup>51</sup> Frantz, J.H. and Jochen, V. Schlumberger. October, 2005. "Shale Gas - When your gas reservoir is unconventional so is our solution." White Paper. [http://www.slb.com/media/services/solutions/reservoir/shale\\_gas.pdf](http://www.slb.com/media/services/solutions/reservoir/shale_gas.pdf)

<sup>52</sup> Pennsylvania State University web site: Thursday, January 17, 2008. "Unconventional natural gas reservoir could boost U.S. supply." Penn State Live. <http://live.psu.edu/story/28116>

<sup>53</sup> Williams, P. July 1, 2007. "Take a look at these shales." *Oil and Gas Investor This Week*. <http://www.allbusiness.com/energy-utilities/energy-utility-sector-performance-oil/8902985-1.html>

<sup>54</sup> February 13, 2008. Cabot Oil & Gas Provides Operations Update. PR Newswire.

<http://news.moneycentral.msn.com/ticker/article.aspx?Feed=PR&Date=20080213&ID=8190652&Symbol=COG>

<sup>55</sup> February 21, 2008. "Atlas Energy Resources, LLC Increases Estimated Reserve Potential From the Marcellus Shale to Between 4 and 6 Tcf Due to Continued Drilling Success." Market Wire.

<http://news.moneycentral.msn.com/ticker/article.aspx?Feed=MW&Date=20080221&ID=8222265&Symbol=ATLS>

<sup>56</sup> Pennsylvania State University web site: Thursday, January 17, 2008. "Unconventional natural gas reservoir could boost U.S. supply." Penn State Live. <http://live.psu.edu/story/28116>

**Dominion Resources, drilling in north-central West Virginia:** A conventional vertical well into the Marcellus “would cost” about \$1 million, while the cost of a horizontal well would rise to about \$3 million.<sup>58</sup>

**Range Resources:** Range expects that a vertical well in a development program could be drilled for approximately \$900,000.<sup>59</sup>

## 1.7 Hydraulic fracturing

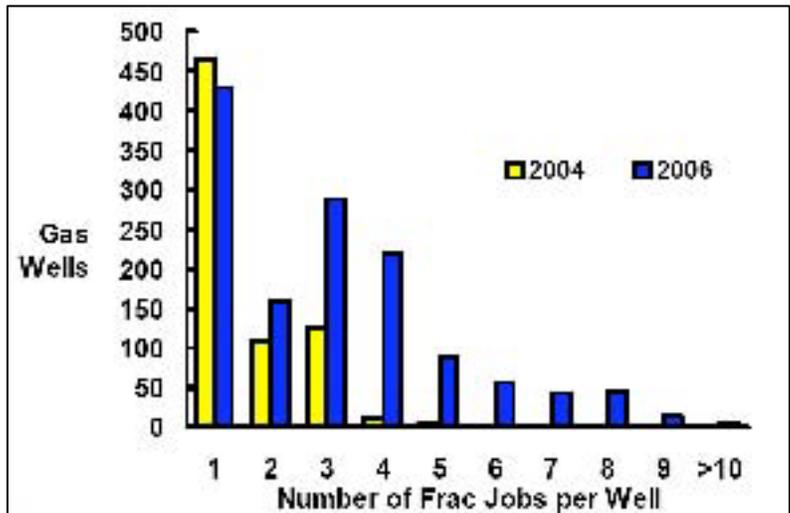
According to Schlumberger, an oil and gas service company, for almost all gas shale wells the rock around the wellbore must be stimulated or hydraulically fractured before a well can produce significant amounts of gas.<sup>60</sup>

According to the Independent Oil and Gas Association of West Virginia, in 2006 there were three primary “camps” regarding what to use to fracture Marcellus shale: straight nitrogen gas, nitrogen foam, and slickwater.<sup>61</sup>

The slickwater fracturing system was initially developed for the Barnett Shale. Early in 1997, Mitchell Energy tried the first slickwater frac (also called a light sand frac). It used 800,000 gallons of water along with 200,000 pounds of sand.<sup>62</sup>

Slickwater fracs require much more water than a typical sand and water frac. This type of frac has proven to be a cost effective system in the Barnett Shale and is being expanded into Haynesville, Marcellus, Woodruff, and Fayetteville shales.<sup>63</sup>

According to Schlumberger, slickwater (a low-viscosity water-based fluid and



**Figure 1. Number of hydraulic fracturing stimulations (“fracs”) on Barnett shale wells.**

**Source:** Cambridge Energy Research Associates, IHS Energy. “Changing geography of North American natural gas.” April, 2008. <http://www.ingaa.org/File.aspx?id=6422>

<sup>57</sup> Pletcher, J. May 19, 2008. “Drillers access mile-deep gas deposits in what may be new ‘gold rush’.” *Herald Standard*.

[http://www.heraldstandard.com/site/news.cfm?newsid=19696240&BRD=2280&PAG=461&dept\\_id=468387&rfi=6](http://www.heraldstandard.com/site/news.cfm?newsid=19696240&BRD=2280&PAG=461&dept_id=468387&rfi=6)

<sup>58</sup> Morris, J. March 23, 2008. “Getting ready for a gusher.” *Charleston Gazette*.

<http://wvgazette.com/News/Business/200803220388?page=2&build=cache>

<sup>59</sup> Williams, P. July 1, 2007. “Take a look at these shales.” *Oil and Gas Investor This Week*. <http://www.allbusiness.com/energy-utilities/energy-utility-sector-performance-oil/8902985-1.html>

<sup>60</sup> Frantz, J.H. and Jochen, V. Schlumberger. October, 2005. “Shale Gas - When your gas reservoir is unconventional so is our solution.” White Paper. [http://www.slb.com/media/services/solutions/reservoir/shale\\_gas.pdf](http://www.slb.com/media/services/solutions/reservoir/shale_gas.pdf)

<sup>61</sup> Myers, R. (BJ Services). October, 2006. “Perforating For Stimulation: A Contrarian Approach,” *IOGA News*, p.8. Published by the Independent Oil and Gas Association of West Virginia. <http://www.iogawv.com/newsFiles/newsletteroct06.pdf>

<sup>62</sup> Smith, T. March 2007 “Producing Gas From Shales,” *GEO ExPro*, p. 49.

<http://www.geoexpro.com/sfiles/4/13/5/file/gasfromshales.pdf>

<sup>63</sup> STW Resources Inc. web site: “Hydraulic Fracturing.” <http://www.stwresources.com/waste-water.html>

proppant) is more commonly used in deeper high-pressure shales, while nitrogen-foamed fracturing fluids are commonly pumped on shallower shales and shales with low reservoir pressures.<sup>64</sup> At least two companies operating in the Marcellus shale agree with this analysis.

Range Resources is experimenting with Barnett-like horizontal wells and slick-water fractures that, while more expensive, are expected to greatly increase the productivity of their Marcellus wells.<sup>65</sup> But according to Jeff Ventura, chief operating officer with Range Resources, slickwater fracking isn't optimal in the southern area because of the low pressure.<sup>66</sup>

Cabot Oil and Gas recently reported that it deepened several wells to the Marcellus and determined that slick water stimulation was more effective than nitrogen fracs in the higher pressured Marcellus section.<sup>67</sup>

If this is the case, then landowners in the overpressured regions in the northern part of the play can expect to see a lot more water truck activity than landowners in the southern part of the Marcellus shale.

### 1.7.1 Water use and associated issues

There is almost no information on the amount of water used by companies drilling the Marcellus shales. According to one newspaper report, Chief Oil & Gas expected to use about 800,000 gallons of water and 250,000 pounds of sand to fracture a vertical well in Mifflin Township (this is approximately the same amount of water and sand used in the first slickwater frac performed in the Barnett Shale). According to a Chief Oil and Gas representative, a horizontal well would require much more water and sand.<sup>68</sup>

Experience in the Barnett shales suggests that horizontal wells can require up to five times the water used by vertical wells.

- According to the Railroad Commission of Texas, slickwater fracturing of a Barnett shale vertical well can use more than 1.2 million gallons (28,000 barrels) of water, while the fracturing of a horizontal well can use more than 3.5 million gallons (over 83,000 barrels) of water.<sup>69</sup>
- Devon Energy reports that its Barnett Shale horizontal wells in the Fort Worth Basin require approximately 3.5 million gallons of fresh water.<sup>70</sup>
- Researchers at Texas A&M University estimate that horizontal wells, undergoing multi-stage fracs, can use between 5 and 6 million gallons of water.<sup>71</sup>

Of course, it must not be assumed that the water requirements in the Marcellus shale are going to be the same as the water requirements in the Barnett shale. But until companies begin to actually report water

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<sup>64</sup> Frantz, J.H. and Jochen, V. Schlumberger. October, 2005. "Shale Gas - When your gas reservoir is unconventional so is our solution." White Paper. [http://www.slb.com/media/services/solutions/reservoir/shale\\_gas.pdf](http://www.slb.com/media/services/solutions/reservoir/shale_gas.pdf)

<sup>65</sup> Riestenberg, D., Ferguson, R., Kuuskraa, V. October 25, 2007. "New Plays, Prospects, Resources Continue to Emerge." *redOrbit*. [http://www.redorbit.com/news/business/1116934/new\\_plays\\_prospects\\_resources\\_continue\\_to\\_emerge/index.html](http://www.redorbit.com/news/business/1116934/new_plays_prospects_resources_continue_to_emerge/index.html)

<sup>66</sup> Brown, D. April, 2007. "If It's Shale, It's Probably in Play," *Explorer*. Association of American Petroleum Geologists. [http://www.aapg.org/explorer/2007/04apr/beyond\\_barnett.cfm](http://www.aapg.org/explorer/2007/04apr/beyond_barnett.cfm)

<sup>67</sup> Reuters. February 13, 2008. "Cabot Oil & Gas Provides Operations Update." <http://www.reuters.com/article/pressRelease/idUS10059+14-Feb-2008+PRN20080214>

<sup>68</sup> Thompson, D. February 21, 2008. Texas drilling company hopes second gas well in county will be productive." *Sun Gazette*. <http://www.chiefoperating.com/images/PDFs/Sun-Gazette%202-21-08%20Frac%20job.pdf>

<sup>69</sup> Railroad Commission of Texas web site: June 4, 2007. "Water Use in the Barnett Shale." [http://www.rrc.state.tx.us/divisions/og/wateruse\\_barnettshale.html](http://www.rrc.state.tx.us/divisions/og/wateruse_barnettshale.html)

<sup>70</sup> Jay Ewing, Devon Energy. February 29, 2008. "Taking a Proactive Approach to Water Recycling in the Barnett Shale." *Fort Worth Business Press Barnett Shale Symposium*, p.9. <http://www.barnettshalenews.com/documents/EwingPres.pdf>

<sup>71</sup> Burnett, D.B. and Vavra, C.J. August, 2006. *Desalination of Oil Field Brine - Texas A&M Produced Water Treatment*. <http://www.pe.tamu.edu/gpri-new/home/BrineDesal/MembraneWkshpAug06/Burnett8-06.pdf>

use, the Barnett shale examples provide a rough idea of the potential water requirements for Marcellus hydraulic fracturing operations.

It is important to note that a well drilled in the Marcellus shale may have to be fracked several times over the course of its life to keep the gas flowing, and that each fracking operation may require more water than the previous one. According to Halliburton, an oil and gas service company:

*"It has been established that only 10% of GIP [gas in place] is recovered with the initial completion. Refracturing the shale can increase the recovery rate by an additional 8% to 10%. Simple reperforation of the original interval and pumping a job volume **at least 25% larger than the previous frac** has produced positive results in vertical shale wells."*<sup>72</sup> [Emphasis added]

There has been an increase in the number of wells being refractured in the Barnett Shale – in some cases, the wells are refractured as many as 10 times. (See Figure 1)

Not only will refracking require tremendous amounts of water to be used and disposed of, but it will also disrupt the lives of the people living close to the well.

The millions of gallons of water must be transported by truck to the well site prior to a fracture treatment. In Johnson County, TX, when wells are horizontally fractured (requiring up to 5 million gallons of water), a single well can have more than 100 water-haulers servicing the well during fracture stimulation.<sup>73</sup> Then, the flow back (waste water) from the fracking operation may require as many as 700 truckloads to transport the fluids to a disposal facility.<sup>74</sup> (Flow back is the fracturing fluid and possibly water from the formation, itself, that returns to the surface after the formation has been hydraulically fractured.)

According to Chief Oil and Gas, "any water that can be reclaimed" from its Marcellus shale fracking operations is removed and shipped to a waste water treatment plant.<sup>75</sup> Regardless of whether the water is shipped to a disposal or treatment facility, there is going to be a lot of traffic for a short period of time.

Water or waste haulers are going to be using county and local roads, and sharing space with normal traffic. This is not only disruptive to the local community, but it can also be destructive to the roads. This has become a problem for at least one county in Texas that is dealing with Barnett shale truck traffic. According to Parker County Commissioner Jim Webster, the road "looked like it'd been hit by a bomb." Webster billed three gas companies \$265,000 for the damage.<sup>76</sup>

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<sup>72</sup> Halliburton. Jan. 2007. "Developing Gas Shale Reserves ." *Advances in Unconventional Gas*. A Hart Energy Publication. p. 28.

<http://www.halliburton.com/public/pe/contents/Brochures/Web/H05270.pdf>

<sup>73</sup> Global Petroleum Research Institute (Texas A&M University) web site: "Conversion of Oil Field Produced Brine to Fresh Water."

<http://www.pe.tamu.edu/gpri-new/home/BrineDesal/BasicProdWaterMgmt.htm>

<sup>74</sup> Burnett, D., Vavra, C and Fox, B. December 14, 2006. "Better than 1" of Rain on a West Texas Ranch-New Technology to Clean up Oil Field Brine." Presentation at the RPSEA Produced Water Forum, New Mexico Institute of Mining and Technology.

[http://www.rpsea.org/forums/produced\\_burnett.pdf](http://www.rpsea.org/forums/produced_burnett.pdf)

<sup>75</sup> Thompson, D. February 21, 2008. "Texas drilling company hopes second gas well in county will be productive." *Sun Gazette*.

<http://www.chiefoperating.com/images/PDFs/Sun-Gazette%202-21-08%20Frac%20job.pdf>

<sup>76</sup> Grable, R.C. Feb. 29, 2008. "Saltwater Disposal and Other "Hot Issues" in Urban Drilling." Presentation at the Fort Worth Business Press Barnett Shale Breakfast Symposium.

<http://www.barnettshalenews.com/documents/Grable%20Barnett%20Shale%20Symposium%20Powerpoint%20Presentation.pdf>

## 1.7.2 Fracking chemicals

In the slickwater fracs used in the Barnett shale, additives may include: friction reducers, biocides, surfactants and scale inhibitors. Hydrochloric acid is also used as part of the fracturing process.<sup>77</sup>

The Endocrine Disruption Exchange has researched some of the chemicals used in oil and gas development in western states. While it is not known if the same chemicals are used in the shale fracs, the TEDX information can provide some background on the types of chemicals and potential health effects that may be associated with "typical" friction reducers, biocides, surfactants and scale inhibitors.<sup>78</sup>

## 1.8 Produced water

Produced water is water that is removed from an oil or gas well. This water is naturally present in the oil or gas formation. In some shales, water is mixed with the gas in the formation. In these situations, the water must be removed to allow the gas to flow (this is similar to coalbed methane production).

*"Removing the hydrodynamic trap on the shale is the key to producing shale gas. This is accomplished with a large sump drilled downward from the lowest point in the well bore. Water is produced to the surface for disposal in approved SWD (salt water disposal) wells with electric submersible pumps. As the water pressure in the fractures is removed from the shale, the gas begins to release through open natural fractures."*<sup>79</sup>

It is not known whether or not there will be produced water associated with Marcellus shale wells. Whether or not a Marcellus shale well produces water will very likely vary from region to region, as in other gas shale plays there is this type of variation.

The other issue to consider is that formations above or below the Marcellus shale may contain water. If hydraulic fractures created during the stimulation of a Marcellus shale well penetrate into adjacent water-bearing formations, that water could be produced from the Marcellus well.

This has been an issue in the Barnett shale, where the Ellenberger formation is a known water source. In some areas, the Viola/Simpson formation lies between the Barnett shale and the Ellenberger. But in other areas, the Viola/Simpson pinches out. In these areas, "stimulation of the Lower Barnett . . . can lead to high water production."<sup>80</sup>

### 1.8.1 Gas shales with produced water

- Barnett shale gas wells can produce a lot of water. According to U.S. Geological Survey data some wells produce about as much wastewater as oilfields do (a median 1,638 gallons of produced water per thousand cubic feet of Barnett shale gas). In Denton County, gas wells produce even more

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<sup>77</sup> Schein, G. Dale Resources, LLC. Feb. 29, 2008. "Hydraulic Fracturing in Gas Shale Plays – Are they all the same?" Presented to the Fort Worth Business Press Barnett Shale Breakfast Symposium. [www.barnettshalenews.com/documents/GarySchein-FtWorthBusinessPress-ShaleCompletions-022908.pdf](http://www.barnettshalenews.com/documents/GarySchein-FtWorthBusinessPress-ShaleCompletions-022908.pdf)

<sup>78</sup> The Endocrine Disruption Exchange web site: <http://www.endocrinedisruption.com/>

<sup>79</sup> Oil-Gas-News.com web site: "New Albany Shale Gas Play, Illinois Basin." <http://www.oil-gas-news.com/index.php?module=article&view=14&33f64fc6c7bbe85bace445f0fe7bc649=131593413bf86c5dd52f431c4da62210>

<sup>80</sup> Grieser, B., Shelley, B., Johnson, B.J., Fielder, E.O., Heinze, J.R. and Werline, J.R. 2006. "Data Analysis of Barnett Shale Completions." SPE Paper 100676. This paper was prepared for presentation at the SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, U.S.A., 24–27 September 2006.

[www.spe.org/atce/2006/technical/documents/spe1006741.pdf](http://www.spe.org/atce/2006/technical/documents/spe1006741.pdf)

water (a median 2,226 gallons, for every thousand cubic feet of gas).<sup>81</sup> Devon Energy reports that in its Barnett Shale wells, some amount of water is produced for the life of the well, and the amount produced varies from close to zero to 400-500 barrels per day.<sup>82</sup>

- One company extracting gas from the New Albany shales in the Illinois Basin has said that it achieves peak gas production following a 6- to 12-month period of removing water from the shales known as “dewatering”).<sup>83</sup>
- The Antrim shale in Michigan also contains water that must be removed in order to achieve maximum gas production rates. In the case of Antrim shale, 12- to 18-months of dewatering may be required before peak production rates are achieved.<sup>84</sup>

## 1.8.2 Gas shales that produce little or no water

- The Lewis shale formation, found primarily in the San Juan Basin of New Mexico and Colorado, is said to produce very little water.<sup>85</sup>
- According to two sources, the Fayetteville shales in Arkansas produce little or no water along with the gas.<sup>86</sup>

## 1.9 Radioactivity

Subsurface formations may contain low levels of radioactive materials such as uranium and thorium and their daughter products, radium 226 and radium 228.

Shales may contain radioactive elements. For example, in Ohio, naturally occurring radioactive material (NORM) typically appears in trace amounts throughout the state. In Ohio, radioactive material is found not only within shale, but also within glacially deposited granitic and metamorphic rocks.<sup>87</sup>

Other Devonian-age shales have enough radioactive material to have been considered as potential low-grade resources of uranium.<sup>88</sup> The Marcellus is considered to be a “highly radioactive” shale.<sup>89</sup>

According to Terry Engelder, geosciences professor at Penn State University, the Marcellus shale is relatively more radioactive than other geological formations. This fact does not appear to concern

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<sup>81</sup> Heinkel-Wolfe, P. November 11, 2007. “Radioactive waste surfaces at Texas gas sites,” *Denton Record-Chronicle*. [http://www.dallasnews.com/sharedcontent/dws/news/localnews/stories/DN-norms\\_11wes.ART.East.Edition1.420fc23.html](http://www.dallasnews.com/sharedcontent/dws/news/localnews/stories/DN-norms_11wes.ART.East.Edition1.420fc23.html)

<sup>82</sup> Jay Ewing, Devon Energy. February 29, 2008. “Taking a Proactive Approach to Water Recycling in the Barnett Shale.” *Fort Worth Business Press Barnett Shale Symposium*. <http://www.barnettshalenews.com/documents/EwingPres.pdf>

<sup>83</sup> January 2006. Shale Gas. A Supplement to Oil and Gas Investor. <http://www.oilandgasinvestor.com/pdf/ShaleGas.pdf>

<sup>84</sup> US Energy Investor. Jan. 2005. *The Bright Future of Shale Gas*. [http://www.admiralbav.com/global/contentserver/files/1022/151596\\_The\\_Bright\\_Future\\_of\\_Shale\\_Gas.pdf](http://www.admiralbav.com/global/contentserver/files/1022/151596_The_Bright_Future_of_Shale_Gas.pdf)

<sup>85</sup> US Energy Investor. Jan. 2005. *The Bright Future of Shale Gas*. [http://www.admiralbav.com/global/contentserver/files/1022/151596\\_The\\_Bright\\_Future\\_of\\_Shale\\_Gas.pdf](http://www.admiralbav.com/global/contentserver/files/1022/151596_The_Bright_Future_of_Shale_Gas.pdf)

<sup>86</sup> J.A. Veil. August, 2007. “Trip Report for Field Visit to Fayetteville Shale Gas Wells.” Argonne National Laboratory report ANL/EVS/R-07/4. p. 17. [http://www.ead.anl.gov/pub/doc/ANL-EVS\\_R07-4TripReport.pdf](http://www.ead.anl.gov/pub/doc/ANL-EVS_R07-4TripReport.pdf) AND January 2006. Shale Gas. A Supplement to Oil and Gas Investor. p. 19. <http://www.oilandgasinvestor.com/pdf/ShaleGas.pdf>

<sup>87</sup> Ohio Department of Natural Resources. October 14, 1997. “Ground Water Quality.” Division of Water Fact Sheet 97-47. <https://ohiodnr.gov/Portals/7/pubs/pdfs/fctsh147.pdf>

<sup>88</sup> Dyni, J.R. U.S. Geological Survey. 2003. “Geology and Resources of Some World Oil Shale Deposits.” *Oil Shale*. Vol. 20, No. 3. p. 235. [http://pubs.usgs.gov/sir/2005/5294/pdf/sir5294\\_508.pdf](http://pubs.usgs.gov/sir/2005/5294/pdf/sir5294_508.pdf)

<sup>89</sup> Hill, D.G., Lombardi, T.E. and Martin, J.P. 2004. “Fractured Shale Gas Potential in New York.” *Northeastern Geology And Environmental Sciences*. Vol. 26. p. 8. [http://www.pe.tamu.edu/wattenbarger/public\\_html/Selected\\_papers/-/Shale%20Gas/fractured%20shale%20gas%20potential%20in%20new%20york.pdf](http://www.pe.tamu.edu/wattenbarger/public_html/Selected_papers/-/Shale%20Gas/fractured%20shale%20gas%20potential%20in%20new%20york.pdf)

Engelder. In an article in the *Times Tribune*, Engelder is quoted as saying that he thinks the radioactivity is "in such low concentrations that it does not bother anyone."<sup>90</sup>

In the oil and gas industry, radioactive materials known as "Naturally Occurring Radioactive Materials" or NORM, can be brought to the surface through oil or gas wells. This can happen in a number of ways, including:

- When fluids that are present in the radioactive formation are pumped out of the well.
- The natural gas, itself, may contain radon gas, a radium daughter.

According to the Railroad Commission of Texas, because the levels of radioactive substances are typically so low, the NORM in produced waters and natural gas is not a problem "unless it becomes concentrated in some manner."<sup>91</sup> There are a number of ways this concentration can occur:

- Through temperature and pressure changes that occur in the course of oil and gas production operations;
- Radium 226 and 228 in produced waters may react with barium sulfate to form a scale in well tubulars and surface equipment;
- Radium 226 and 228 may occur in sludge that accumulates in pits and tanks; and
- During gas processing activities, NORM can occur as radon gas in the natural gas stream. Radon decays to Lead-210, then to Bismuth-210, Polonium-210, and finally to stable Lead-206. Radon decay elements occur as a film on the inner surface of inlet lines, treating units, pumps, and valves principally associated with propylene, ethane, and propane processing streams.

Because the radioactive materials become concentrated on oil and gas-field equipment, the highest risk of exposure to oil and gas NORM is to workers employed to cut and ream oilfield pipe, remove solids from tanks and pits, and refurbish gas processing equipment.<sup>92</sup>

### 1.9.1 NORM and the Barnett shale

According to data from the Texas Department of State Health Services, 140 sites with high levels of NORM (either well sites or sites containing oil and gas equipment) were decontaminated between January, 2005 and November, 2007. Twenty-five (25) of the decontamination sites were in Denton, Tarrant and Wise counties, the core counties of the Barnett shale.<sup>93</sup> (To read more about NORM in the Barnett shale, see the four-part series by Peggy Heinkel-Wolfe:

[http://www.dentonrc.com/sharedcontent/dws/drc/specialprojects/drilling/stories/DRC\\_NORM1\\_11-11.1fb48b711.html](http://www.dentonrc.com/sharedcontent/dws/drc/specialprojects/drilling/stories/DRC_NORM1_11-11.1fb48b711.html))

### 1.9.2 NORM and the Marcellus shale

As mentioned previously, the Marcellus shale is considered to be relatively "highly radioactive." In New York, the Marcellus shale is closer to the surface than in other regions where the shale can be thousands

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<sup>90</sup> Legere, L 05/06/2008. Tallying the environmental cost. *Times Tribune*. [http://www.thetimes-tribune.com/site/news.cfm?newsid=19663539&BRD=2185&PAG=461&dept\\_id=415898&rft=6](http://www.thetimes-tribune.com/site/news.cfm?newsid=19663539&BRD=2185&PAG=461&dept_id=415898&rft=6)

<sup>91</sup> Railroad Commission of Texas web site: "NORM – Naturally Occurring Radioactive Material" <http://www.rrc.state.tx.us/divisions/og/key-programs/norm.html>

<sup>92</sup> Railroad Commission of Texas web site: "NORM – Naturally Occurring Radioactive Material" <http://www.rrc.state.tx.us/divisions/og/key-programs/norm.html>

<sup>93</sup> Heinkel-Wolfe, P. November 11, 2007. "Radioactive waste surfaces at Texas gas sites." *Denton Record-Chronicle*. [http://www.dallasnews.com/sharedcontent/dws/news/localnews/stories/DN-norms\\_11wes.ART.East.Edition1.420fc23.html](http://www.dallasnews.com/sharedcontent/dws/news/localnews/stories/DN-norms_11wes.ART.East.Edition1.420fc23.html)

of feet below the surface. Due to the proximity of the shale to the surface, there have been several studies on the radioactivity of the Marcellus shale in New York.

For example, in Onondaga County, NY, the radioactive substance radon ( $^{222}\text{Rn}$ ) was measured in indoor air in the basements of 210 homes. All of the homes underlain by Marcellus shale had indoor air levels of  $^{222}\text{Rn}$  above 4 picocuries per liter (pCi/L), and the average concentration in these homes was 8.8 pCi/L,<sup>94</sup> which is more than twice the U.S. Environmental Protection Agency's "action level" (the level when it is recommended that homeowners try to reduce the radon) of 4 pCi/L. The average national indoor radon level is 1.3 pCi/L.<sup>95</sup>

In 1991, the Pennsylvania Bureau of Oil and Gas Management (BOGM) and Bureau of Radiation Protection conducted surveys of NORM at oil and gas sites in the state.<sup>96</sup> The highest concentration of Radium 226 was found in a "deep gas" sample (4,685 pCi/L). Although three samples of Marcellus gas were tested, the BOGM survey report did not report the concentrations of Radium in those samples. Drill cuttings were sampled from one formation "that was suspected to be a problem." This was the Onondaga formation, which is located below the Marcellus formation. The drill cutting concentrations there ranged from 0.65 pCi/g to 1.031 pCi/g.<sup>97</sup>

At the time, the BOGM concluded that, "our survey results indicate that NORM is not a problem at oil and gas well sites in Pennsylvania."<sup>98</sup> But, at the time, the agency did not appear to sample drill cuttings and sludge from any Marcellus well sites.

It would be very useful if the state would conduct a study specific to natural gas sites that are tapping into the Marcellus formation, as it is a known source of radioactive shales.

As the Marcellus shale continues to be developed, it will be important to understand the radioactivity of the various waste streams that are produced – e.g., produced water, gas, pit/tank sludge, drill cuttings and others.

It is especially important to understand the potential radioactivity of wastes that may be disposed of in areas that are located close to residences or public facilities such as schools. For example, during drilling, there may be a large volume of radioactive Marcellus shale rock removed (i.e., the drill cuttings), especially from horizontally drilled wells.<sup>99</sup> If these rock wastes are disposed of by on-site burial or land-spreading, the radioactivity may become an issue for those living nearby. Radioactive wastes should be taken to a facility that is designed to handle low-level radioactive waste.

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<sup>94</sup> Banikowski and Hand (1987). Cited in L.C.S. Gundersen, R.B. Wanty. 1992. *Field Studies of Radon in Rocks, Soils, and Water*. (CRC Press) P. 216. <http://books.google.com/books?id=yIirVOF-gpYC&printsec=frontcover&dq=Field+Studies+of+Radon+in+Rocks,+Soils,+and+Water&ei=neUySOGIJZTqgP--ntAq&sig=7ZQvIT42OWGYdUEIRKU0r-YHzM0#PPA216.M1>

<sup>95</sup> U.S. Environmental Protection web site: "Why is radon the public health risk that it is?" <http://www.epa.gov/radon/healthrisks.html>

<sup>96</sup> Pennsylvania Bureau of Oil and Gas Management and Bureau of Radiation Protection September, 1992. *NORM Survey Summary*. <http://www.dep.state.pa.us/dep/deputate/minres/oilgas/NORM.pdf>

<sup>97</sup> Pennsylvania Bureau of Oil and Gas Management and Bureau of Radiation Protection September, 1992. *NORM Survey Summary*. p.9. <http://www.dep.state.pa.us/dep/deputate/minres/oilgas/NORM.pdf>

<sup>98</sup> Pennsylvania Bureau of Oil and Gas Management and Bureau of Radiation Protection September, 1992. *NORM Survey Summary*. p.1. <http://www.dep.state.pa.us/dep/deputate/minres/oilgas/NORM.pdf>

<sup>99</sup> For example, a horizontal well may travel 3000 feet through the Marcellus formation. (Source: Marilyn Alva. Friday April 4, 2008. "A Texas Natural-Gas Driller Looks To Strike It Rich In Appalachia." <http://biz.yahoo.com/ibd/080404/newamer.html?v=1>) If the diameter of the drilled hole is 6", the volume of rock removed would be 590 cubic feet of radioactive shale.

Pennsylvania does not have specific oil and gas regulations that pertain to NORM, but other states do. To find out more about these regulations, go to: [http://norm.iogcc.state.ok.us/reg/dsp\\_statereg.cfm](http://norm.iogcc.state.ok.us/reg/dsp_statereg.cfm).

## 1.10 Metals and acid-producing minerals

Marcellus shales are known, in some regions, to contain acid-producing minerals such as pyrite and sulfides.

- The Pennsylvania Department of Conservation and Natural Resources publishes a map that indicates which formations are likely to contain acid-forming minerals. The lower part of the Marcellus formation is on the map.<sup>100</sup>

In 2003, an exit ramp was being constructed to the Mifflin County, PA, Industrial Park. The roadcut exposed the Marcellus Formation. Shortly after excavation, acidic, iron-rich water began to flow out of the exposed Marcellus. Pyrite, an iron sulfide formed under reducing (no oxygen) conditions, was deemed to be the source of the acid drainage.<sup>101</sup>

When pyrite is exposed to air and water, it breaks down and forms sulfuric acid and iron hydroxide – a phenomenon well known in the mining industry. The acid-producing reaction occurs as long as the pyrite continues to be exposed to air and water. If these conditions persist, acid will be produced until all of the sulfide in the rock is used up. At some mining sites, it is predicted that acid will be generated for hundreds or even thousands of years from the sulfide mineral waste created during the mining process.<sup>102</sup>

While the amount of acid-generating rock material removed during the drilling of the Marcellus shale would be very minimal compared to the amount of material exposed during a mining operation, the drill cuttings may still contain enough pyrite to cause problems. The weathering of pyritic shales can result in “acid generation, metal mobility, and salinization of ground and surface water.”<sup>103</sup>

Metal mobility is caused because the acidic drainage can dissolve toxic metals (e.g., copper, aluminum, cadmium, arsenic, lead and mercury) that are present in the surrounding rock or soil.<sup>104</sup> Black shales, like the Barnett, Marcellus, Fayetteville, New Albany and others, are often enriched in trace metals. The U.S. Geological Survey has found high concentrations of arsenic, cobalt, chromium, molybdenum, nickel, vanadium and zinc in stream sediments near outcrops of pyrite-rich Devonian black shale.<sup>105</sup>

If toxic metals are mobilized, the metals could move through the soil and contaminate surface or groundwater.

It is possible that the potential for some Marcellus shale drill cuttings to generate acid and mobilize metals

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<sup>100</sup> Pennsylvania Department of Conservation and Natural Resources web site.

<http://www.dcnr.state.pa.us/topogeo/openfile/acidmaplayers.aspx#8>

<sup>101</sup> Thomas A. McElroy. 2006. “Geology of Oz aka the U.S. Route 22–522 Industrial Drive Interchange.” *Pennsylvania Geology*. Vol. 36, No. 2/3. Pennsylvania Department Of Conservation And Natural Resources, Bureau Of Topographic And Geologic Survey.

[http://www.dcnr.state.pa.us/topogeo/pub/pageolmag/pdfs/v36n2\\_3.pdf](http://www.dcnr.state.pa.us/topogeo/pub/pageolmag/pdfs/v36n2_3.pdf)

<sup>102</sup> Earthworks. “Hard Rock Mining: Acid Mine Drainage.” Fact Sheet. [http://www.earthworkSACTION.org/pubs/FS\\_AMD.pdf](http://www.earthworkSACTION.org/pubs/FS_AMD.pdf)

<sup>103</sup> Michele Tuttle, Paul Briggs, and Cyrus Berry. “Speciation and Isotopic Composition of Sulfide and Sulfate Minerals.” USGS.

[http://crustal.usgs.gov/projects/aqueous\\_geochemistry/S\\_SO4\\_minerals.html](http://crustal.usgs.gov/projects/aqueous_geochemistry/S_SO4_minerals.html)

<sup>104</sup> Earthworks. “Hard Rock Mining: Acid Mine Drainage.” Fact Sheet. [http://www.earthworkSACTION.org/pubs/FS\\_AMD.pdf](http://www.earthworkSACTION.org/pubs/FS_AMD.pdf)

<sup>105</sup> Tuttle, M.L.W., Goldhaber, M.B., and Breit, G.N. (U.S. Geological Survey. 2001. “Mobility of metals from weathered black shale: the role of salt efflorescences.” Paper No. 78-0 presented at GSA Annual Meeting, November 5-8, 2001. Boston, Massachusetts.

[http://gsa.confex.com/gsa/2001AM/finalprogram/abstract\\_26237.htm](http://gsa.confex.com/gsa/2001AM/finalprogram/abstract_26237.htm)

in rock or soil may preclude them from being buried on-site or land spread. To address this, for example, according to the Pennsylvania Code:

§ 78.63 (b) A person may not dispose of residual waste, including contaminated drill cuttings, at the well site unless the concentration of contaminants in the leachate from the waste does not exceed the maximum concentration stated in § 261.24 Table I (relating to characteristic of toxicity).<sup>106</sup>

## 1.11 Hydrogen sulfide

Hydrogen sulfide (H<sub>2</sub>S) gas occurs naturally in some geologic formations and in groundwater from those formations. It is formed from decomposing underground deposits of organic matter such as decaying plant material. It may be found in deep or shallow wells. H<sub>2</sub>S often is present in wells drilled in shale or sandstone, or near coal or peat deposits or oil fields.<sup>107</sup>

According to the Nebraska Cooperative Extension:

*Hydrogen sulfide is flammable and poisonous. Usually it is not a health risk at concentrations present in household water, except in very high concentrations. While such concentrations are rare, hydrogen sulfide's presence in drinking water when released in confined areas has been known to cause nausea, illness and, in extreme cases, death.*<sup>108</sup>

In some areas, Devonian shales are known to contain hydrogen sulfide. For example:

- According to the Ohio State University Extension, in central Crawford County poor quality water is common from the Devonian shale bedrock. Wells drilled into shale or limestone in this region “may produce water that contains objectionable quantities of hydrogen sulfide (rotten egg odor). In general, the probability of obtaining sulfur in objectionable amounts increases with the depth drilled.”<sup>109</sup>
- In Clark County, KY, salt, hydrogen sulfide, and iron are the usual “objectionable” constituents in water from the New Albany shale.<sup>110</sup>
- In Derry Township, PA, the Hamilton Group formation, which includes Marcellus shale and Mahantango shale/siltstone/sandstone, contains water that “may have high iron and sulfur content; hydrogen sulfide is a common gas.”<sup>111</sup>

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<sup>106</sup> Pennsylvania Code. Title 25, Environmental Protection. Chapter 78. Oil and Gas Wells.

<http://www.pacode.com/secure/data/025/chapter78/s78.63.html>

<sup>107</sup> Varner, D., Skipton, S., Jasa, P., and Dvorak, B. August, 2004. *Drinking Water: Sulfates and Hydrogen Sulfide*. Nebraska Cooperative Extension. G96-1275-A. <http://www.ianr.unl.edu/PUBS/water/g1275.htm>

<sup>108</sup> Varner, D., Skipton, S., Jasa, P., and Dvorak, B. August, 2004. *Drinking Water: Sulfates and Hydrogen Sulfide*. Nebraska Cooperative Extension. G96-1275-A. <http://www.ianr.unl.edu/PUBS/water/g1275.htm>

<sup>109</sup> Prochaska, S.C., Jones, A.W., Brown, L.C., and Boone, K.M. *Crawford County Ground-Water Resources*. Ohio State University Extension. AEX-490.17. Ohio Water Resources Education Project, in cooperation with: ODNR Division of Water; Ohio EPA; USGS, Ohio District; and Ohio Department of Health (ODH). [http://ohioline.osu.edu/aex-fact/0490\\_17.html](http://ohioline.osu.edu/aex-fact/0490_17.html)

<sup>110</sup> Carey, D.I., Stickney, J.F. (Kentucky Geological Survey). 2005. *Groundwater resources of Clark County*. County Report 25, Series XII. Report prepared for the Kentucky Water Resource Development Commission. <http://www.uky.edu/KGS/water/library/gwatlas/Clark/GWavailability.htm>

<sup>111</sup> Gehringer-Roth Associates. June, 1997. *Official Comprehensive Plan*. “Section III. Natural and Cultural Features.” Prepared for Derry Township, Mifflin County, PA. p. 28.

## 1.12 Well spacing/density

Initially, when a new natural gas field is developed, well spacing depends on the state's regulations. It is common for operators to be allowed one well per section (640 acres) or drilling unit, unless they can prove to state regulators that more wells are required to extract as much of the gas resource as possible.

According to the *Oil and Gas Investor*, "As plays become further developed and the reservoir is better understood, downspacing begins."<sup>112</sup>

This is starting to occur in the Barnett shale. While many wells are spaced at 160 acres, Devon Energy is starting to infill – as of March, 2008, the company announced it had drilled 57 wells at 40-acre spacing (or, according to the company, 500 feet apart), and that it plans to drill pilot wells at 20-acre spacing this year (according to the company, that's **250 feet apart**).<sup>113</sup> In 2006, Devon was already drilling horizontal wells at 20-acre spacing;<sup>114</sup> presumably, the 2008 pilot wells are being drilled in a different part of the Barnett shale.

Devon Energy is not the only company drilling wells closer together. According to Denbury Resources, "wells in the Barnett Shale were initially drilled by spacing horizontal wells approximately 1,500' apart and drilling 3,000' to 4,500' laterals. As our development progressed we began testing wells at various spacings of 750' and subsequently 500' along with other operators in the Barnett. . . We have recently begun testing well spacings less than 500'.<sup>115</sup>

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<http://www.elibrary.state.pa.us/dldoc.asp?fn=4208718944mcp0035.pdf> (Section III)

<http://www.elibrary.state.pa.us/dldoc.asp?fn=4208718944mcp0005.pdf> (Cover page)

<sup>112</sup> Haines, L. Jan. 1, 2006. "Downspacing for gas: the power of siting wells closer together is boosting the production numbers of tight-gas plays and operators' reserves." *Oil and Gas Investor*.

[http://www.accessmylibrary.com/coms2/summary\\_0286-12484483\\_ITM](http://www.accessmylibrary.com/coms2/summary_0286-12484483_ITM)

<sup>113</sup> Devon Energy. March 28, 2008. Barnett Shale and Resource Update. Teleconference and Webcast. Oklahoma City. Slide 34. <http://www.devonenergy.com/ir/Documents/032808 - Barnett and Resource Update.pdf>

<sup>114</sup> Devon Energy web site: May 2, 2006. "Devon Energy to Acquire Barnett Shale-Focused Chief Holdings; Updates Barnett and Companywide Growth Outlook." Investor Relations - News Release.

<http://investor.dvn.com/phoenix.zhtml?c=67097&p=irol-newsArticle&ID=850512&highlight=>

<sup>115</sup> Denbury Resources web site: Dec. 31, 2007. "Texas and the Barnett Shale.

[http://www.denbury.com/Barnett\\_Shale.htm](http://www.denbury.com/Barnett_Shale.htm)



**Table 1. Typical spacing of different gas shales**

<b>Antrim Shale (MI)</b> <sup>116</sup>	<ul style="list-style-type: none"> <li>Michigan has set 40- to 80-acre spacing for Antrim wells</li> </ul>
<b>Barnett Shale (TX)</b> <sup>117</sup>	<ul style="list-style-type: none"> <li>Wells are typically drilled at 40- to 160-acre spacing</li> <li>Some companies are testing wells at 20-acre spacing</li> </ul>
<b>Fayetteville Shale (AR)</b> <sup>118</sup>	<ul style="list-style-type: none"> <li>Arkansas Oil and Gas Commission Rule B-43 allows 40-acre spacing (16 wells per 640-acre-unit)</li> <li>Wells must be 560' from unit boundaries and other unconventional wells in the Fayetteville Shale.</li> </ul>
<b>New Albany Shale (IL, IN, KY)</b>	<ul style="list-style-type: none"> <li>In 2006, wells were being drilled on 160-acre spacing<sup>119</sup></li> <li>By 2008, wells were being drilled at 80-acre spacing.<sup>120</sup></li> </ul>
<b>Ohio Shale (OH)</b> <sup>121</sup>	<ul style="list-style-type: none"> <li>40 – 160 acre spacing</li> </ul>
<b>Woodford (OK)</b>	<ul style="list-style-type: none"> <li>Spacing for the Woodford shale to date is 640 acres<sup>122</sup></li> <li>Chesapeake Energy is drilling horizontal wells on 160-acre spacing<sup>123</sup></li> <li>Several companies like Newfield Exploration<sup>124</sup> and Petroquest<sup>125</sup> are planning to drill on 80-acre and 40-acre spacing.</li> </ul>

As seen from Table 1, several other shale formations have experienced the same trend of being drilled on tighter spacing as time goes by.

Due to the variability of the Marcellus shale formation, it is likely that spacing will vary from region to region. Some companies have begun estimating the spacing required to develop their leases. For example:

<sup>116</sup> Michigan Department of Environmental Quality. <http://www.deq.state.mi.us/documents/deq-ogs-land-oilandgas-spacing-Antrim.pdf>

<sup>117</sup> Schein, G. Dale Resources, LLC. Feb. 29, 2008. "Hydraulic Fracturing in Gas Shale Plays – Are they all the same?" Presented to the *Fort Worth Business Press Barnett Shale Breakfast Symposium*. <http://www.barnettshalenews.com/documents/GarySchein-FtWorthBusinessPress-ShaleCompletions-022908.pdf>

<sup>118</sup> Arkansas Oil and Gas Commission. May 5, 2008. *North Arkansas Field Rule Summaries*. Field B-43. p. 2. [http://www.aogc.state.ar.us/Field%20Rules/Field%20Rule%20Summaries%20-%20North%20Arkansas%20\(Active%20List\).pdf](http://www.aogc.state.ar.us/Field%20Rules/Field%20Rule%20Summaries%20-%20North%20Arkansas%20(Active%20List).pdf) Also Arkansas Oil and Gas Commission Rules. pp.52,53. <http://www.aogc.state.ar.us/OnlineData/Forms/Rules%20and%20Regulations.pdf>

<sup>119</sup> 2006. Shale Gas – A supplement to Oil and Gas Investor. p.16 <http://www.oilandgasinvestor.com/pdf/ShaleGas.pdf>

<sup>120</sup> Schein, G. Dale Resources, LLC. Feb. 29, 2008. (See footnote 110)

<sup>121</sup> Schein, G. Dale Resources, LLC. Feb. 29, 2008. (See footnote 110)

<sup>122</sup> Apr 07, 2008. "Longer legs, multilaterals under study in Arkoma Woodford shale gas play," *Oil and Gas Journal*. Volume: 106, Issue: 13.

<sup>123</sup> Feb 14, 2008. "Chesapeake Energy Corporation Announces 2007 4th Quarter and Full-Year Production and Proved Reserves." *Business Wire*. [http://findarticles.com/p/articles/mi\\_m0EIN/is\\_2008\\_Feb\\_14/ai\\_n24263202/pg\\_7](http://findarticles.com/p/articles/mi_m0EIN/is_2008_Feb_14/ai_n24263202/pg_7)

<sup>124</sup> 2006. Shale Gas – A supplement to Oil and Gas Investor. p. 17. <http://www.oilandgasinvestor.com/pdf/ShaleGas.pdf>

<sup>125</sup> Petroquest. Jan. 9, 2008. Presentation at the Prichard Capital 5<sup>th</sup> Annual Energy Conference. p. 11. <http://www.sec.gov/Archives/edgar/data/872248/000095013408000327/h52968exv99w1.htm>

- Chesapeake Energy's targeted results for vertical Marcellus Shale wells are \$1.6 million to develop 1.25 bcfe on approximately 160-acre spacing. The company has not yet developed a model for targeted results from horizontal wells in the play.<sup>126</sup>
- XTO, which recently acquired Marcellus shale leases in West Virginia, is seeking 80- to 100-acre well spacing.<sup>127</sup>
- Atlas Energy has announced that it believes it will be able to develop its southwestern Pennsylvania Marcellus acreage through vertical drilling on approximately 40-acre spacing.<sup>128</sup>

In July of 2007, the West Virginia Oil and Gas Commission created special field rules that apply only to Chesapeake Energy's wells in certain counties. The Commission ruled that the Marcellus wells drilled by Chesapeake were considered to be "deep wells," and that they were to be spaced a minimum of 1000 feet apart and 100 feet from a lease line or unit boundary.<sup>129</sup>

The Commission's ruling was controversial because there was some uncertainty about whether or not the wells were indeed "deep" wells, and not shallow wells, and whether or not the 1000-foot spacing was arbitrarily set (allowing wells to be situated too close together). The West Virginia Coal Association and some oil and gas drillers have now filed a Petition for a "Writ of Prohibition" in the West Virginia Supreme Court of Appeals to prevent the Oil and Gas Conservation Commission from declaring Marcellus wells to be "statutory" "deep wells". For more information on this issue, visit the West Virginia Surface Owners' Rights Organization web site: [http://www.wvsoro.org/curent\\_events/index.html#well\\_spacing](http://www.wvsoro.org/curent_events/index.html#well_spacing).

The Supreme Court's decision may affect how many Marcellus shale wells are ultimately drilled in West Virginia.<sup>130</sup>

One other issue to be considered, when it comes to well spacing, is that in many areas where the Marcellus shale may be drilled, there are also other oil and gas producing formations. Well drilled into these other formations also require well pads and infrastructure. Consequently, in some areas, Marcellus wells are going to increase the overall density of oil and gas wells.

It is possible to drill numerous wells from a single well pad. If landowners are concerned about Marcellus shale wells adding to the density of existing wells, drilling a Marcellus well on an existing oil or non-gas-shale pad may reduce the overall 'footprint' of development on the surface.

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<sup>126</sup> Feb. 14, 2008. "Chesapeake Energy Corporation Announces 2007 Fourth Quarter and Full-Year Production and Proved Reserves." *Business Wire*.

[http://findarticles.com/p/articles/mi\\_m0EIN/is\\_2008\\_Feb\\_14/ai\\_n24263202/pg\\_7](http://findarticles.com/p/articles/mi_m0EIN/is_2008_Feb_14/ai_n24263202/pg_7)

<sup>127</sup> April 15, 2008. "XTO Buys Marcellus Shale Stake." <http://www.thestreet.com/story/10412173/1/xto-buys-marcellus-shale-stake.html>

<sup>128</sup> February 21, 2008. "Atlas Energy Resources, LLC Increases Estimated Reserve Potential From the Marcellus Shale to Between 4 and 6 Tcf Due to Continued Drilling Success." *Market Wire*.

<http://news.moneycentral.msn.com/ticker/article.aspx?Feed=MW&Date=20080221&ID=8222265&Symbol=ATLS>

<sup>129</sup> Oil and Gas Conservation Commission of West Virginia. "In the matter of the request by Chesapeake Appalachia, L.L.C., for an order from the Commission establishing special field rules in Boone, Kanawha, Lincoln and Mingo counties, West Virginia." Dockets No. 179, 180 and 181. Cause No. 164, Order No. 1. (The Commission Docket rulings are available on the West Virginia Surface Owner Rights Organization web site: [http://www.wvsoro.org/curent\\_events/chesapeak\\_order.pdf](http://www.wvsoro.org/curent_events/chesapeak_order.pdf))

<sup>130</sup> Morris, J. March 23, 2008. "Getting ready for a gusher," *Charleston Gazette*. <http://wvgazette.com/News/Business/200803220388?page=1&build=cache>

It is also may be possible to drill several Marcellus shale wells from the same pad – if they are drilled horizontally. In the Barnett shale, “horizontal technology offers the advantage of drilling multiple wellbores off a single pad, thus leaving a small footprint and enabling access to targets significantly removed from permitted drilling locations. This is a major plus for the Barnett play given that the city of Fort Worth sits atop a vast quantity of Barnett gas.”<sup>131</sup>

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<sup>131</sup> Durhan, L.S. Feb. 2006. “Texas Reservoir Chased Under Urban Setting Barnett Shale a Stimulating Play.” *Explorer*. Association of American Petroleum Geologists.  
[http://www.aapg.org/explorer/2006/02feb/barnett\\_shale.cfm](http://www.aapg.org/explorer/2006/02feb/barnett_shale.cfm)