Marcellus Shale Geology and Oil and Gas Drilling and Production

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Natural gas (mainly methane) is a fossil fuel but it makes significantly less CO₂ per BTU than oil and coal. It also makes much less or no mercury SO₂, NOₓ and other pollutants.

### Exhibit 4: Combustion Emissions (Pounds/billion BTU of Energy Input)

<table>
<thead>
<tr>
<th>Air Pollutant</th>
<th>Combusted Source</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Natural Gas</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>117,000</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>40</td>
</tr>
<tr>
<td>Nitrogen oxides (NOₓ)</td>
<td>92</td>
</tr>
<tr>
<td>Sulfur dioxide (SO₂)</td>
<td>0.6</td>
</tr>
<tr>
<td>Particulates (PM)</td>
<td>7.0</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.750</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*Sources: EIA, 1998*
Natural gas is used for heat, cooking, power generation, industrial processes and can be used to power cars and trucks – all of these could and would probably grow if we were certain that there was a cheap, reliable source of natural gas.
It looked like natural gas production had peaked in 2001 and was declining leading to higher prices – unlocking of shale gas changed that and has led to increased production since 2007 and a decrease in price. The price decline associated with the rise of shale gas is currently saving New Yorkers roughly $4 billion/year and the US about $100 billion/year.
There are numerous marine black shales in the US with potential to produce gas – potential for hundreds or thousands of TCF
US Shale Gas

• From less than 1% of US production in 2000, shale gas now accounts for 30% of US natural gas production
• Marcellus first produced in 2006, today the Marcellus produces 4BCF/D or 6% of US total
• Some projections have Marcellus producing 25% of US total in 2020
• GHG emissions in US declining, at least in part because old coal plants are being replaced by new gas plants
Organic-Rich Black Shale

- Organic-rich marine black shales are the source of most of the oil and gas produced in the United States and are now considered potential reservoirs themselves.
- The organic matter in marine black shales is mainly algae, plankton, diatoms and spores that are preserved during deposition.
- When organic-rich shales are buried and heated some of the organic matter turns into oil and some turns into gas.
Conventional Petroleum System shows oil and gas migrating from source rock to reservoir - shales typically source rocks and seals on more porous reservoirs – in this case the source is the reservoir.
Core samples from Marcellus – light colored material are fossils that are partly silicified.
As the organic matter expels oil and gas, pores form and much of the gas that is produced comes from these tiny pores. They aren’t well connected and need fractures to flow.
Marcellus on surface here

Probably economic below 4000 feet (~1200m), maybe as little as 3000 ft (~900m)
There is a minimum thickness below which it will not be economic that is also linked to TOC content – 50 feet (16m)?
Wells in this area producing >10MMCF/D with some up to 30 MMCF/D, cumulative production of 5-15BCF/80 acres.

Wells in wet gas area expected to produce up to 280 MBL and 4 BCF gas - this area is now very popular due to liquids production.
Thicker sections deeper than 4000 feet most likely to be developed first – how shallow can this play work? How far east can it work?
Thermal Maturity

Dry gas should be produced east of the 1.1 $R_o$ line – some have suggested that there may be a “line of death” above $R_o$ values of 3.1- the jury is still out on this but it is a critical question.
After considering the depth, thickness, TOC content and thermal maturity this map shows the areas of probable and possible economic Marcellus production – if only the red area is developed, this could still mean >60 TCF of gas in NY alone.
Drilling Rig - This is only present for the drilling of the well(s) and is then moved on to the next well.

Steering motor and bit for drilling directional and horizontal wells.
At several points during the drilling of the well, steel pipe called casing will be run into the hole and cemented in place – they squeeze cement in between the pipe and bedrock to prevent fluids from migrating outside the pipe – this is a key step that is essential to a good frac job and production well.
6-8 horizontal wells can be drilled from each surface location and about 1 square mile (or more) can be drained from each surface location – in this case the total land surface disrupted should be around 1% of the total.
Hydraulic Fracturing of Rocks

• Perforations are made in the steel casing
• Water, sand and some additives are pumped into the perforations in isolated stages at high enough pressure to fracture the rock (not an explosion)
• This process was first done in the early 1900s and hundreds of thousands of oil and gas wells (and many water wells) have been “fraced” over the years

Wylie, Eberhard, and Mullen, 2007

At the surface fluids and or proppants are pumped into the wellbore under high pressure to enhance production and creating areas for hydrocarbons to move from the reservoir into the well bore
Frac job on a Marcellus Shale Well – 2-10 million gallons of water (with ~0.1-0.5% additives) and sand are pumped at high pressure into each well in multiple stages to induce fractures and prop them open – Average frac job is now about 5 million gallons in 12-20 stages
Microseismic detectors can be used to see how far the fractures extend from the wellbore.

This is a map and cross section view of microseismic data around a horizontal well that shows fracture development in a four stage frac job (each color represents a stage).

Wells commonly drilled perpendicular to principle compressive stress.
Using special microseismic data, we can see exactly where the fractures form – this figure shows a summary of the depth of the well, highest fracture and base of the fresh water for numerous wells in PA and WV.
At about 2500 feet the stress field changes and above that only horizontal fractures will form – so economics and simple physics make it extremely unlikely that fractures will extend upward into fresh water from below.
“Fracking”

- It has become clear that the way different groups define “fracking” has become part of the problem.
- Fracking in the oil and gas business and to regulators means the actual hydraulic fracturing of the well.
- Fracking in some of the media and in some opposing groups has come to include all aspects of drilling, casing the well, hydraulic fracturing, and other parts of the operation.
- So when companies or regulators say “fracking doesn’t contaminate groundwater” they mean the actual process of hydraulic fracturing – groundwater contamination is possible due to surface spills or methane migration but these are not “fracking”
State and Federal Agencies Say Fracking Does Not Appear to Contaminate Groundwater

• “I’m not aware of any proven case where the fracking process itself has affected water” said Lisa Jackson, Obama’s head of the EPA

• The NYSDEC and regulatory agencies in other states all say they are not aware of any cases where hydraulic fracturing has contaminated groundwater

• Continued focus on “fracking” as the problem distracts from real issues
Methane Migration

• In some areas where Marcellus drilling is occurring, there is naturally occurring methane in the fresh water aquifer or in the sandstones immediately below the aquifer – the gas migrated upward and into these formations over millions of years.

• In some cases drilling and poor cementing of casing have caused an increase in methane concentrations in nearby water wells that is sourced from these shallow horizons (not from fracking of the Marcellus).

• This is a real issue.

• But this is also an issue that has gone on for decades that has been studied extensively by the PA DEP.
Marcellus is down here

This is where the shallow gas can occur that causes problems

>5000 feet (1 mile)

Marcellus is down here
Natural gas is found in water wells in NY drilled into shallow gas-bearing strata far from areas of production.
In Dimock, PA three wells intersected a shallow gas zone (not the Marcellus)
They did not set intermediate casing over that zone which would have been required in NY
Gas migrated up behind the casing and got into the groundwater
Unrelated to fracking
Methane Migration – NE PA

• It is not related to fracking
• The gas comes from the aquifer itself or from shallow formations just below the aquifer, not the much deeper Marcellus
• Methane is a natural substance that can be naturally occurring in water wells – its presence does not necessarily indicate a problem with drilling
• If there is a significant increase in methane concentrations during and just after drilling, it could be a problem with drilling or casing
• Improved drilling and cementing practices and close regulation can minimize this problem
This group from Duke came on to the scene and with little background information or understanding of the geology pronounced that methane levels were 17 times greater in areas where gas drilling was occurring than in areas where gas drilling was not occurring and then implied that this was due to fracking.

It is a very poorly done study with many flaws.

If they had talked to the local regulators for ten minutes they would never have written this paper.
• Howarth et al. from Cornell University published a study that received a lot of media attention that suggested that shale gas has greenhouse gas emissions equal to or greater than coal, largely due to methane emissions.

• The lead author is a biologist and anti-fracking activist who does not appear to have much knowledge of gas and coal industry practices which led to some significant errors including:
  – An unrealistic assumption about how much gas was lost during drilling and completion (it would have been about $1 million worth per well but he stated that it was only worth $75)
  – Did not know that most gas that is lost is flared and released as CO₂ not methane
  – Did not realize that most gas lost in pipelines is from extracting non-methane and also using methane to run compressors (which release CO₂ not methane)
GHG Emissions

• Subsequent studies by more knowledgeable groups at NETL, Carnegie Mellon, University of Maryland, and several others all find that on a life-cycle basis shale gas emits about 55% of the GHGs that coal does per unit of energy created.

• This is very important, because the policy implication of Howarth et al.’s work would be to keep burning coal instead of switching to much cleaner burning gas (for GHG’s as well as mercury, particulates, etc.)
A Broader Point

• Many people writing news articles and some academics writing papers on shale gas have little or no knowledge of how gas wells are drilled, completed, hydraulically fractured, or subsurface geology and other important background information.

• Most of the people who do know something about these topics are either in the industry or regulators of the industry (like the DEC) with a few in academia and it is very easy to make mistaken interpretations without this knowledge.

• These are complex topics that require time and an interest in science and engineering to understand – this makes fertile ground for misinformation to grow.
Conclusions

• Shale gas is a game changer for US and global energy future
• It is enabling a shift from coal to cleaner-burning natural gas and causing the price of gas to move substantially lower
• There is high potential for the Marcellus Shale to produce large quantities of gas in NY
• Some misinformation has worked its way into this issue – there are real problems but much focus has been on issues that aren’t significant problems