Natural Gas Drilling in the Marcellus Shale
Katherine Meek, David Vaglia, Dean Gamache, Bryan Regis, and Neyvin De Leon
Edited and re-arranged by L. Cathles
Outline

- The Resource (#3)
- The Issues (#22)
- Laws and Regulations (#71)
- Replacing AES Cayuga (#78)
- References (#86)
The Resource

The Marcellus and Utica (#4-12)

Production, price, royalties (#13-19)

Financials (#20-21)
The Marcellus and Other Gas Resources
The Utica Shale- The Local Resource

http://geology.com/articles/utica-shale/
Utica Shale

- Thicker than the Marcellus Shale
- Covers more area than the Marcellus Shale
- Still in early stages of development
- Tends to be a few thousand feet below the Marcellus
- Generally not tapped if Marcellus is present
- Has a higher carbonate content and a lower clay content than the Marcellus so it behaves differently to hydraulic fracturing

http://geology.com/articles/utica-shale/
Depth of the Utica
Depth of the Utica

Generalized Cross Section
Utica and Marcellus Shale
Ohio to Pennsylvania

Elevation of the Base of the Utica Shale (feet below sea level)

http://geology.com/articles/utica-shale/
Thickness of the Utica vs the Marcellus

Thickness of the Utica Shale
(Includes the Point Pleasant and Antes Shale)

http://geology.com/articles/utica-shale/

http://www.marcellus.psu.edu/resources/maps
Ohio Utica Shale Acreage and Maturity

HBP - 22,387 Ac.
TERM - 5,000 Ac.

Source Rock Maturation Status Based on Combined CAI to Ro Regression Equation (Hulver, 1997; Rowan, 2006)

http://www.bakerwell.com/Utica_Shale_Acreage.html
Horizontal Drilling Permits Issued in Ohio for the Utica Shale

Cumulative number of permits issued

http://geology.com/articles/utica-shale/
Utica Shale

- Companies such as Exxon and Chesapeake are currently buying leases in the area
- Estimates of total gas content ranges from 2 trillion to 69 trillion cubic feet of natural gas (the Marcellus is estimated to contain about 363 TCF)
- Total oil content is said to be around 1.3 and 5.5 billion barrels of oil
- Due to untested nature of the Utica, Drilling companies still prefer to tap the proven resource, the Marcellus
- In the future the infrastructure from the Marcellus development could be applied to the Utica

http://oilshalegas.com/uticashale.html
http://geology.com/articles/utica-shale/
Gas wells in the Marcellus, Haynesville, Barnett and Fayetteville shale often yield between 0.2 and 2.0 million cubic feet per day. Higher and lower rates do occur.

Acreages can be different depending on mineral rights and lease agreements.
Well Production Rate initially $\sim 2 \times 10^6$ cubic ft per day; total production $>2$ bcf/well

Marcellus Shale

4.2 bcf EUR Type Curve
- IP Rate: 4.0 mmcf/day
- First month average: 3.5 mmcf/day
- Finding Cost: 1.28 ($/mcf)$
- Well Cost: $4.5$ mm

Annual Decline Rate:
- 70%
- 33%
- 22%
- 17%
- 13%
- 11%
- 9%
- 8%
- 7%
- 6%

End of Year

0 1 2 3 4 5 6 7 8 9 10

Production Rate (mmcf/day)

Cumulative Production (bcf)
Lowest gas prices are paid by companies who purchase the gas as it flows from a well. This is known as the "wellhead price". These buyers receive a low price because they purchase very large amounts of gas that has not been processed or transported.

http://geology.com/usgs/marcellus-shale/
Your Natural Gas Royalty!

- Your **Natural Gas Royalty** is a combination of:
  - **Wellhead Price**
  - **Average Production Rate** of the well
  - **How Many Acres** do you own within your production unit
  - **Royalty Rate**
The royalty rate should be in your lease agreement. It is the share of gas produced from the well that you will be paid for!

The customary N.Y. royalty rate is 12.5 percent of the value of gas produced by a well. Higher royalty rates are sometimes paid by aggressive buyers for highly desirable properties.
### Natural Gas Royalty Estimate

#### Here is the data that you entered

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5</td>
<td>Your royalty rate.</td>
</tr>
<tr>
<td>$4.20</td>
<td>Average wellhead gas price.</td>
</tr>
<tr>
<td>2</td>
<td>Average well production rate in millions of cubic feet per day.</td>
</tr>
<tr>
<td>1</td>
<td>Acres you own within the well's production unit.</td>
</tr>
<tr>
<td>1</td>
<td>Number of acres in the well's production unit.</td>
</tr>
<tr>
<td>$31,500.00</td>
<td>Your expected royalty payment per MONTH (before expenses).</td>
</tr>
</tbody>
</table>

Note: This is 12.5% of the gross value of the gas produced from one well tapping ~80 acres. Deduct expenses if royalty is based on net value. Production will decline rapidly as well ages.

Low End Results for Royalty

Natural Gas Royalty Estimate

<table>
<thead>
<tr>
<th>Here is the data that you entered</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5</td>
<td>Your royalty rate.</td>
</tr>
<tr>
<td>$4.20</td>
<td>Average wellhead gas price.</td>
</tr>
<tr>
<td>0.2</td>
<td>Average well production rate in millions of cubic feet per day.</td>
</tr>
<tr>
<td>1</td>
<td>Acres you own within the well's production unit.</td>
</tr>
<tr>
<td>1</td>
<td>Number of acres in the well's production unit.</td>
</tr>
<tr>
<td>$3,150.00</td>
<td>Your expected royalty payment per MONTH (before expenses).</td>
</tr>
</tbody>
</table>

Note: This is 12.5% of the gross value of the gas produced from one well tapping ~80 acres. Deduct expenses if royalty is based on net value. Production will decline rapidly as well ages.
Revenues to NYS

- NYS currently received $746,000 in lease payments on state owned land
- Hydraulic fracturing could increase employment and income by $621 million and $3.7 billion
- Personal income tax in NYS is 5%
- At 5%, increased income would yield State $31 to 185 million in tax revenues
Financial Analysis: Benefits

Important Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Information Derived from Cathles Slide 78</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price of Gas</td>
<td>$5/kscf</td>
</tr>
<tr>
<td>Area</td>
<td>4047 m²/acre</td>
</tr>
<tr>
<td>Producible Area</td>
<td>1.475 kscf/m²</td>
</tr>
</tbody>
</table>

Important Conversions

1 bbl of oil = 6000 scf of gas
1 bbl of oil = 6.12 x 10⁹ J
1 W = J/sec

Calculation of the Value of Gas/Acre

\[
\frac{5 \text{ kscf}}{1.475 \text{ kscf/m²}} \times \frac{4047 \text{ m²}}{1 \text{ acre}} = \$30,000/\text{acre}
\]

Power Density after 30 yrs of Production

\[
\frac{1475 \text{ scf}}{6000 \text{ scf}} \times \frac{1 \text{ bbl}}{1 \text{ bbl}} \times \frac{6.12 \times 10^9 \text{ J}}{30 \text{ yrs}} \times \frac{1 \text{ yr}}{365 \text{ days}} \times \frac{1 \text{ day}}{24 \text{ hour}} \times \frac{1 \text{ hour}}{3600 \text{ sec}} = 1.6 \text{ J/sec/m²} = 1.6 \text{ W/m²}
\]

Net Present Value, 1 well

<table>
<thead>
<tr>
<th>NPV(20y) (millions)</th>
<th>Levelized Break Even Sales Price of Gas ($/1000 cf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>$2.824</td>
</tr>
<tr>
<td>HIGH</td>
<td>$6.652</td>
</tr>
</tbody>
</table>

REX Energy Corp. 2009
The Issues

CO2 (#24-26)

Water (#27-40)

Roads (#41-51)

Pipelines (#52-66)

Wildlife (#67-70)
# Hydrofracking and the Environment

## Opposing Viewpoints

<table>
<thead>
<tr>
<th>Pro-Hydrofracking</th>
<th>Anti-Hydrofracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Immense Economic Benefits: Marcellus Shale projected to offer $30,000/acre of producible gas ...potential to produce energy equivalent of 30 million gallons of petroleum oil</td>
<td>• Environmental Concerns</td>
</tr>
<tr>
<td>• Natural gas more efficient and emits less CO₂ than coal</td>
<td>• Groundwater Contamination</td>
</tr>
<tr>
<td>• No link between horizontal fracturing and water contamination (Lisa Jackson, EPA)</td>
<td>• Wastewater Disposal</td>
</tr>
<tr>
<td>• Regulations or bans should be imposed by the DEC at the state level rather than through local governments</td>
<td>• Overuse of Water Resources</td>
</tr>
<tr>
<td>• Innovation requires risk, don’t be crippled into inaction by fear!</td>
<td>• Infrastructure Damage</td>
</tr>
<tr>
<td></td>
<td>• Are these environmental concerns valid? Let’s investigate.</td>
</tr>
</tbody>
</table>
CO2 (#25-27)
**CO₂ Savings Compared to Coal**

To generate 1 million BTU

- **Chemical Reaction**:
  
  \[
  90 \text{ lb coal} \quad + \quad 187 \text{ lb O}_2 \quad \rightarrow \quad 257 \text{ lb CO}_2
  \]

- **CH₄ Leakage**:
  
  \[
  853 \text{ cubic ft CH}_4 \quad + \quad 152 \text{ lb O}_2 \quad \rightarrow \quad 85.5 \text{ lb H}_2\text{O} \quad + \quad 104.5 \text{ lb CO}_2
  \]

  \[0.4 \text{ wt }% \text{ leakage (EPA)} \times 20 \text{ (CH}_4 \text{ is 20 times more potent as a greenhouse gas than CO}_2\text{)} = 8 \text{ lb CO}_2\]

- **CH₄ Leakage**:
  
  \[8 \text{ lb CO}_2 + \quad = \quad 112.5 \text{ lb CO}_2\]

Craig 2011

### Energy Source Comparison

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>CO₂ Wt. (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>257.0</td>
</tr>
<tr>
<td>Gas</td>
<td>112.5</td>
</tr>
</tbody>
</table>

- Burning gas reduces CO₂ emissions by 50% compared to coal burning

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>30</td>
</tr>
<tr>
<td>Gas (cogeneration)</td>
<td>60</td>
</tr>
</tbody>
</table>

- Burning gas 2X more efficient than burning coal lowering CO₂ emissions even further...estimates project a 78% reduction in CO₂ emissions
Emissions

CO₂ Emission=(2.6kg/l)x(3.785l/gal)x(1gal/5mile)x(20mph)x(1hr/trip)= 39 kg per trip

CO₂ Emission per Well =(39 kg/trip)*(1ton/907.84kg)*(200 trips/year)= 8.6 Tons per Year

Total CO₂ Emission due to Trucks= (8.6 tons)x(2100 wells)=**18,043 Tons per Year**

In 2006, Miliken power station emitted **2,370,486 Tons of CO₂**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Gasoline Fuel</th>
<th>Diesel Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/Hp-hr (power output)</td>
<td>lb/MMBtu (fuel input)</td>
</tr>
<tr>
<td>NOₓ</td>
<td>5.0</td>
<td>1.63</td>
</tr>
<tr>
<td>CO</td>
<td>3.16</td>
<td>0.99</td>
</tr>
<tr>
<td>TOC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>exhaust</td>
<td>6.8</td>
<td>2.10</td>
</tr>
<tr>
<td>evaporative</td>
<td>0.30</td>
<td>0.09</td>
</tr>
<tr>
<td>crankcase</td>
<td>2.2</td>
<td>0.69</td>
</tr>
<tr>
<td>refueling</td>
<td>0.5</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Water (#29-41)
Groundwater Contamination

Naturally Occurring Radioactive Materials (NORMS)

- Include U, Th, and Ra found in geological formations which are brought to the surface during gas drilling and abstraction.

- At the surface, NORMS accumulate in scales and sludges on and within drilling and processing equipment or in brines and sediments within holding tanks or ponds.

- Considered a radiation hazard at elevated concentrations.
<table>
<thead>
<tr>
<th>Location</th>
<th>Mean $^{226}$ Ra Value (dpm/L)</th>
<th>Mean $^{228}$ Ra/$^{226}$ Ra Activity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seneca</td>
<td>0.040</td>
<td>0.69</td>
</tr>
<tr>
<td>Cayuga</td>
<td>0.046</td>
<td>0.77</td>
</tr>
<tr>
<td>Fall Creek</td>
<td>0.034</td>
<td>0.83</td>
</tr>
<tr>
<td>Salmon Creek</td>
<td>0.067</td>
<td>0.83</td>
</tr>
<tr>
<td>Taughannock Creek</td>
<td>0.031</td>
<td>0.90</td>
</tr>
<tr>
<td>Owasco</td>
<td>0.037</td>
<td>0.80</td>
</tr>
<tr>
<td>Otisco</td>
<td>0.032</td>
<td>0.89</td>
</tr>
<tr>
<td>Skaneateles</td>
<td>0.036</td>
<td>0.85</td>
</tr>
<tr>
<td>Canadice</td>
<td>0.006</td>
<td>1.01</td>
</tr>
<tr>
<td>Hemlock</td>
<td>0.019</td>
<td>0.98</td>
</tr>
<tr>
<td>Honeoye</td>
<td>0.012</td>
<td>0.93</td>
</tr>
<tr>
<td>Conesus</td>
<td>0.013</td>
<td>0.97</td>
</tr>
<tr>
<td>Canandaigua</td>
<td>0.027</td>
<td>0.80</td>
</tr>
</tbody>
</table>

- Waters sampled in Central NY have low Mean $^{226}$Ra values and Mean $^{228}$ Ra/$^{226}$ Ra Activity Ratios >0.5
- Contamination by U/Ra rich, highly saline Marcellus and black shales with Mean $^{228}$ Ra/$^{226}$ Ra Activity Ratios <0.5 can be easily recognized by the isotopic signature of Ra $^{29}$
## World-Wide Average U and Th Content in Igneous, Metamorphic, and Sedimentary Rocks

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>U (ppm)</th>
<th>Th (ppm)</th>
<th>Th/U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultramafic</td>
<td>0.01</td>
<td>0.05</td>
<td>3.6</td>
</tr>
<tr>
<td>Basalt</td>
<td>0.4</td>
<td>1.6</td>
<td>4.0</td>
</tr>
<tr>
<td>Gabbro</td>
<td>0.8</td>
<td>3.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Granite</td>
<td>4.8</td>
<td>21.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Nepheline syenite</td>
<td>14</td>
<td>48</td>
<td>3.4</td>
</tr>
<tr>
<td>Granulite</td>
<td>1.6</td>
<td>7.2</td>
<td>4.5</td>
</tr>
<tr>
<td>Granitic gneiss</td>
<td>3.5</td>
<td>12.9</td>
<td>3.7</td>
</tr>
<tr>
<td>Sandstone</td>
<td>1.4</td>
<td>5.5</td>
<td>3.9</td>
</tr>
<tr>
<td>Shale (gray-green)</td>
<td>3.2</td>
<td>11.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Carbonate</td>
<td>2.2</td>
<td>1.2</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Shale (black carbonaceous)</strong></td>
<td><strong>8.0</strong></td>
<td><strong>1.7</strong></td>
<td><strong>0.2</strong></td>
</tr>
<tr>
<td>Marine phosphorite</td>
<td>76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crustal rocks (avg)</td>
<td>2.5</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Sea water</td>
<td>0.003</td>
<td>10⁻⁵</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

Sources: Rogers and Adams (1969); Gabelman, 1977; Rose, et al (1979); Woodmansee (1975)

- $^{234}U \rightarrow ^{230}Th + ^4He$
- $^{230}Th \rightarrow ^{226}Ra + ^4He$
- $^{292}Th \rightarrow ^{228}Ra + ^4He$

- $^{226}Ra: \tau_{1/2} = 1600$ yrs
- $^{228}Ra: \tau_{1/2} = 5.8$ yrs

- $U: \tau_{1/2} = 4.47 \times 10^9$ yrs
- $Th: \tau_{1/2} = 75.4 \times 10^3$ yrs

- Ra is a NORM and can be used as an isotopic tracer to determine sources and mixing of water bodies
- High salinity of production brines keeps Ra isotopes in solution
Calculation of $^{226}$Ra

Take ratio of half lives \[ \frac{\tau_{1/2, Ra \, 226}}{\tau_{1/2, U \, 234}} = \frac{1600 \text{ years}}{4.47 \times 10^9 \text{ years}} = 3.58 \times 10^{-7} \]

As shown in the figure above, Marcellus contains 65 ppm U

\[ 3.58 \times 10^{-7} \times 65 \text{ ppm} = \frac{2.33 \times 10^{-5} \text{ ppm Ra}}{10^{-6} \text{ ppm}} \]

\[ \frac{1 \text{ pCi}}{1 \text{ g}_{\text{rock}}} = 23.3 \text{ pCi/g}_{\text{rock}} \]

For 2 g$_{\text{rock}}$/cm$^3$, 10% porosity Marcellus Shale

\[ \frac{23.3 \text{ pCi}}{1 \text{ g}_{\text{rock}}} \times \frac{2 \text{ g}_{\text{rock}}}{1 \text{ cm}^3} \times \frac{1 \text{ cm}^3}{1 \text{ mL}} \times \frac{1000 \text{ mL}}{1 \text{ L}} = 430,000 \text{ pCi/L Ra into pore water} \]

\[ \frac{23.3 \text{ pCi}}{1 \text{ g}_{\text{rock}}} \times \frac{1 \text{ g}_{\text{rock}}}{1 \text{ cm}^3} \times \frac{1 \text{ cm}^3}{1 \text{ mL}} \times \frac{1 \text{ mL}}{1 \text{ L}} \times \frac{0.1 \text{ (porosity)}}{1 \text{ L}} = 21,500 \text{ pCi/L Ra into return fluids assuming 5% loading} \]
Hydrofracking fluids are injected into wells under pressure to create cracks and fractures which accelerate gas flow out of rock and into the well.

Hydrofracking fluids are a proppant (sand) and H₂O mixture used to keep cracks from resealing once hydrofracking fluids are withdrawn from the well.

### Chemical Contaminants of Concern in Hydrofracking Fluids

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Mean Sample Conc. (μg/L)</th>
<th>Max. Contaminant Level (μg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene (C₆H₁₂) Carcinogen</td>
<td>479.5</td>
<td>5</td>
</tr>
<tr>
<td>4-nitroquinoline-N-oxide (C₉H₆N₂O₃) Carcinogen/Mutagen</td>
<td>1.39 x 10⁴</td>
<td>(SGEIS 2011)</td>
</tr>
</tbody>
</table>
### Fracking fluid components and functions

<table>
<thead>
<tr>
<th>Fracking fluid components and functions</th>
<th>Chemical component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biocide (0.02%) to prevent bacterial growth</td>
<td>Gluteraldehyde; Nitrilopropionamide</td>
</tr>
<tr>
<td>Gel (0.001%) to carry proppant materials</td>
<td>Guar gum, petroleum distillates</td>
</tr>
<tr>
<td>Corrosion inhibitor (0.0008%) to reduce rust formation</td>
<td>Methanol; ammonium bisulfate</td>
</tr>
<tr>
<td>Slickwater (0.09%) to reduce friction during pumping operations</td>
<td>Polyacrylamide (PAM); petroleum distillates</td>
</tr>
<tr>
<td>Surfactant (0.10%) to enhance recovery of injected water into the well</td>
<td>Methanol; isopropanol; ethoxylated alcohol</td>
</tr>
<tr>
<td>Breaker (0.00006%) to enhance recovery of fracking fluid</td>
<td>Peroxydisulfates</td>
</tr>
<tr>
<td>Additive Type</td>
<td>Main Compound</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Acid</td>
<td>Hydrochloric acid or muriatic acid</td>
</tr>
<tr>
<td>Biocide</td>
<td>Glutaraldehyde</td>
</tr>
<tr>
<td>Breaker</td>
<td>Sodium Chloride</td>
</tr>
<tr>
<td>Corrosion inhibitor</td>
<td>N,n-dimethyl formamide</td>
</tr>
<tr>
<td>Friction Reducer</td>
<td>Petroleum distillate</td>
</tr>
<tr>
<td>Gel</td>
<td>Guar gum or hydroxyethyl cellulose</td>
</tr>
<tr>
<td>Iron Control</td>
<td>2-hydroxy-1,2,3-propanetricarboxylic acid</td>
</tr>
<tr>
<td>Oxygen scavenger</td>
<td>Ammonium bisulfite</td>
</tr>
<tr>
<td>Proppant</td>
<td>Silica, quartz sand</td>
</tr>
<tr>
<td>Scale inhibitor</td>
<td>Ethylene glycol</td>
</tr>
</tbody>
</table>

Arthur 2008
Is Groundwater Contamination a Risk?

**Natural barriers**

- Gas shale resources located 850 ft below potable water table
- Siltstone and shale formations (Hamilton Group and upper Devonian formations) overlying Marcellus prevent vertical migration of fluids
- Shale zones between Marcellus and shallow groundwater zones protect groundwater resources from hydraulic fracture treatments used in the processing of Marcellus
- Varying physical character of shales prevents propagation of fractures across multiple shale zones
Is Groundwater Contamination a Risk? (cont.)

Protection Factors

• Surface casings: cemented steel pipes at the uppermost portion of the well
• Water-based slickwater fracturing fluids contain fewer chemical additives than cross-linked gels
• System designs carry fracturing fluids within closed loops to hold additives, fracturing fluids, mixing equipment, and flowback water within storage tanks, service trucks, or flowlines

**The probability of fracture fluids reaching an underground source of drinking water (USDW) due to failures in the casing or casing cement is estimated to be between $2 \times 10^{-5}$ (1 well in 200,000) and $2 \times 10^{-8}$ (1 well in 200 million) (API)

• In order for injected water to reach USDWs, a number of independent events must occur at the SAME TIME and go UNDETECTED (e.g. leaks in tubing and casing coupled with water movement up borehole past saltwater aquifers) (API)

**Groundwater contamination due to improper handling or disposal of wastewater is still a problem at the SURFACE but can be managed through regulations
Propane Fracking

Environmental Benefits

1) Enhanced Efficiency
- Gas flow more efficient in propane fracking than in hydrofracking
  - Propane Fracking: 100% of propane leaves fractured rocks
  - Hydrofracking: Water can be absorbed into rock and block pathways for gas to escape
- Propane fracking uses 25% of the truck trips that water based fracking employs
  - Reduces impact on roads, noise, dust annoyance, and trucking costs

2) Less Contamination
- Vapor from propane does not carry salts or radioactivity from NORMS
- Propane vapor can be reclaimed, reused, and resold resulting in greater economic benefits

Why hasn’t propane fracking gone mainstream?
- Initial cost of propane > water; propane is flammable while water isn’t
- Technology is new; skeptics want to make sure that propane fracking works before investing in it
- Current infrastructure is in place for water based fracking not propane fracking
Overuse of Water Resources

Effects on Local Water Supply

• 1 to 5 million gallons of water required for drilling and stimulation of a single well

• Will This Stress Local Water Supplies?
  – Maximum approved daily consumptive use is 563 mg/d
  – Hydrofracking 100 pads uses 16.2 mg/d
  – This is only 3% of the total leaving a surplus of ~547 mg/d for other uses

Swartz 2008
Niagara Falls Wastewater Treatment Plant

Bar Screens (removal of large solids) ➔ Grit Removal (small solids) ➔ FeCl₃ (flocculation/coagulation of solids) ➔ Thickening/belt pressing for dewatering and disposal

Solids removed

Carbon beds remove dissolved contaminants ➔ Treatment with H₂O₂ (odor control) and NaOCl (disinfection) before returning to Niagara River

- Capacity 136 mL/d = 55 cfs
- 100 pads/yr need 25 cfs water @ 20% return and no re-use, need 25 cfs *0.2 = 5 cfs treatment

\[
\frac{55 \text{ cfs}}{1 \text{ yr}} \times \frac{100 \text{ pads}}{5 \text{ cfs}} = 1100 \text{ pads/yr treated}
\]
### Injection of Wastewater into Existing Deep Wells

**Important parameters to know before injection**
- Porosity of formation
- Permeability of layer
- Thickness of layer
- Locations of abandoned gas/oil/water wells (i.e. unplugged wells)

**Injection tests required to determine limits of injection capacity**
- If fluid injection overcapacity, pressure will buildup to set off seismic activity

**Best candidates for wastewater injection**
- Oriskany and Medina sandstones
- Potsdam layer
- Non-producing Trenton-Black River wells

**Regulation of disposal wells**
- EPA permit for a Class IID injection well
- DEC State Pollutant Discharge Elimination System (SPDES) permit for brine disposal
- SPDES permit for stormwater runoff
- Municipal Special Use permit if required by local law
- Permission of the landowner

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Tableau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silurian</td>
<td>Lower</td>
<td>Tristates</td>
</tr>
<tr>
<td></td>
<td>Helderberg</td>
<td>Manlius</td>
</tr>
<tr>
<td></td>
<td>Upper</td>
<td>Salina</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vernon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lockport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clinton</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>Sodus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thorold</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medina</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper</td>
<td>Queenston</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lorraine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trenton</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>Trenton-Black River</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>Beekmantown</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Arthur 2008
Roads (#42-51)
Transportation

Number of trucks needed

Increase in traffic

Efficiency of transportation

Emission Analysis
## Truck Loads per Well

Bakken Formation, ND

<table>
<thead>
<tr>
<th>Item</th>
<th>Number of Trucks</th>
<th>Inbound/Outbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (fresh)</td>
<td>80</td>
<td>Inbound</td>
</tr>
<tr>
<td>Water (waste)</td>
<td>400</td>
<td>Inbound</td>
</tr>
<tr>
<td>Frac Tanks</td>
<td>200</td>
<td>Outbound</td>
</tr>
<tr>
<td>Rig Equipment</td>
<td>100</td>
<td>Both</td>
</tr>
<tr>
<td>Drilling Mud</td>
<td>50</td>
<td>Both</td>
</tr>
<tr>
<td>Chemical</td>
<td>4</td>
<td>Inbound</td>
</tr>
<tr>
<td>Cement</td>
<td>15</td>
<td>Inbound</td>
</tr>
<tr>
<td>Pipe</td>
<td>10</td>
<td>Inbound</td>
</tr>
<tr>
<td>Scoria/Gravel</td>
<td>80</td>
<td>Inbound</td>
</tr>
<tr>
<td>Fuel Trucks</td>
<td>7</td>
<td>Inbound</td>
</tr>
<tr>
<td>Frac/cement pumper trucks</td>
<td>15</td>
<td>Inbound</td>
</tr>
<tr>
<td>Workover Rigs</td>
<td>1</td>
<td>Inbound</td>
</tr>
<tr>
<td><strong>Total-One Direction</strong></td>
<td><strong>1,012</strong></td>
<td></td>
</tr>
</tbody>
</table>
Current Estimates

- Tompkins County Council of Governments Gas Drilling Task force estimates 1200 truck loads per well

- 2400 roundtrips per well

- Our county currently experiences 600,000 heavy truck trips per year
## Estimated Well Pads by Town

Tompkins County, NY

<table>
<thead>
<tr>
<th>Town</th>
<th>Number of Pads</th>
<th>Number of Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caroline</td>
<td>36</td>
<td>360</td>
</tr>
<tr>
<td>Danby</td>
<td>12</td>
<td>120</td>
</tr>
<tr>
<td>Dryden</td>
<td>44</td>
<td>440</td>
</tr>
<tr>
<td>Enfield</td>
<td>17</td>
<td>170</td>
</tr>
<tr>
<td>Groton</td>
<td>44</td>
<td>440</td>
</tr>
<tr>
<td>Ithaca</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Lansing</td>
<td>30</td>
<td>300</td>
</tr>
<tr>
<td>Newfield</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Ulysses</td>
<td>14</td>
<td>140</td>
</tr>
<tr>
<td>Total</td>
<td>210</td>
<td>2100</td>
</tr>
</tbody>
</table>

This amounts to 500,000 round trips per year; heavy truck traffic would double (assuming a 10 year well completion period).
Projected Traffic Increase

- 500,000 extra trips per year on main roads
- RT 79 experiences 1,825,000 trips per year
- Small increase in total traffic overall
Road Damage

• “The impact of water hauled to one site (364 trips) is the equivalent of nearly 3.5 million car trips” –Maryland Department of the Environment
Infrastructure Damage

- **Road Damage**
  - 990 truck trips (82.5% of the total 1200 truck trips) from hydraulic fracture procedures and flowback removal
  - 30 ton trucks (on average) + heavy traffic + poor road materials + poor drainage + time = road damage
  - State Road Damage: 5% (negligible)
  - County Road Damage: 20% (low)
  - Town/Municipality Road Damage: 90% (high)

- **Reduction in Truck Usage**
  - Use multi-well pads
    - Consecutive drilling and stimulation of multiple wells from one pad will eliminate the trucking of equipment from single well pad to single well pad
  - Recycle flowback water for fracking operations
  - Centralize water impoundment location so water can be brought in by pipeline instead of by trucks

Percentage of Truck Trips for Various Drilling and Equipment Procedures for a Single Well

- Flowback Water Removal: 22.3%
- Drilling Operations: 17.5%
- Hydraulic Fracture Equipment: 15.6%
- Hydraulic Fracture Water: 44.6%
- SGEIS 2011

Before Drilling

After Drilling
Infrastructure Damage (cont.)

- **Pavement Deflection**
  - Tensile stress (pavement bottom) + compressive stress (surface under load) = pavement deflection
  - Cracks develop when tensile stress > strength of asphalt mix (heavy load)
  - Cracks develop due to flexing of pavement (repetitive actions by small loads)

- **Fatigue Failure**
  - Weight and deflection angle affect the number of cycles to failure
    - Heavy loads bend road more so fewer cycles to failure compared to smaller loads
  - Line with slope of 4 in log-log shape for roads
  - Going from 3 ton car \([3^4 = 81]\) to 30 ton truck \([30^4 = 81,000]\) will mean 1000 times more damage in a single pass

- **Miner’s Hypothesis of Cumulative Damage**
  \[ \sum D = \sum \frac{n_f}{N_f} \]
  \[ D = \% \text{ of damage}, \ n_f = \# \text{ of truck trips}, \ N_f = \# \text{ of cycles to failure} \]
  - Each bend takes percentage of road’s life
  - Road cannot regain lost life
  - Road only fails when \( D > 1 \)
• **Seasonality Effects**
  – Different deflection angles for different seasons
    • Spring Thaw: 135 degrees
    • Late Spring: 90 degrees
    • Middle of Summer: 45 degrees
    • Winter: negligible deflection angle
  – Angle of deflection reflects road strength
    • Roads strongest in winter (smallest deflection angle, greater # of cycles to failure) and weakest during spring thaw (largest deflection angle, fewer # of cycles to failure)
    • Roads gain strength during the late spring, summer, and fall

• **Road Costs**
  – Costs greater for roads in poor condition than for roads in good condition
  – Road User Costs (gas, oil, tires): 90%
  – Cost of Building and Maintaining Road: 10%
Summary

So, to put it all together, the use of trucks for hydrofracking in Tompkins County will not significantly increase overall traffic. Nor will it emit enough CO₂ to make natural gas less attractive than burning coal. However, there will be significant road damage, and this is something the gas companies should pay the County for.
Pipelines (#53-66)
Natural Gas Transport: Pipeline Transmission

Legend:
- Interstate Pipelines
- Intrastate Pipelines

Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System
Current Pipeline Transport Capacity

• “At present, the natural gas pipeline capacity in the Marcellus Shale region is inadequate to carry the volume of gas that will be produced. Several major pipelines are needed to transport millions of cubic feet of gas per day to high population markets. In addition, thousands miles of natural gas gathering systems must be built to connect individual wells to the major pipelines.” –Geology.com

• In Pennsylvania, the current network of pipelines is not equipped to carry the volume of shale gas that is expected to be produced with the necessary pressure to get it to market.
Pipeline of Focus: the Millennium Pipeline

• One of the main transmission pipelines in the Marcellus Region; over 10 other major gathering lines feed into the Millenium.

• This $1.04 billion interstate pipeline was constructed by five major energy/pipeline companies and will be a main transporter of natural gas over the next 50 years.

• This 30-inch diameter pipeline stretches 260 miles across the Southern Tier and Lower Hudson Valley with over 115,130 horsepower of compression along its length.

• The Millennium Pipeline delivers 525,400 dekatherms (154000 MW-hours) of energy to customers every day.
Pipeline Land Usage: Processing, Compressor and Metering Stations
Typical Pipeline Network Components

- The current U.S. pipeline transmission system consists of 180,000 miles of high-strength steel pipe.

- The pipeline company’s primary function is to move large amounts of natural gas thousands of miles from producing regions to “city gate stations”.

- Compressor and metering stations are placed at required distances along the pipe to boost the pressure of the gas that is lost through friction to the pipe walls.

Components include:
- Producing Wells
- Compressor Stations
- Processing Plant
- Metering Stations
- Underground Storage
- City Gate Station
- Regulator/SCADA Center
Pipeline Land Usage: Processing, Compressor and Metering Stations

• Since the gas contained in many areas of the Marcellus Shale is “wet gas” (rich in gas liquids), extra compounds such as butane, propane, and ethane need to be extracted from the gas stream at a processing station before the methane is “pipeline ready”.

• Data readings are taken at the processing station and intermittent metering stations.

• Each compressor station is usually sited on 15 to 22 acres of land and requires an all-gravel access road. Metering stations are usually built adjacent to the ROW itself. Above-ground valves are placed every 5 to 20 miles and use a 40-ft. by 40 ft. area of cleared land on the ROW.

• The Millennium Pipeline has 35 Metering stations, one compressor station, and 10 interconnection points with other company-owned “gathering lines”.
Pipeline Land Usage: ROW

- Pipelines have a specified depth of cover and a ROW (right-of-way) which must remain clear at all times.

- Because of the large diameter of the Millennium Pipeline, a ROW of 70 to 130 feet wide is needed (including through forested areas) to keep the pipe available for maintenance.
Natural Gas Storage

• The three primary types of underground natural storage in the U.S. today are:
  – Depleted natural gas or oil fields (326)
  – Aquifers (43)
  – Salt caverns (31)

• Depleted gas/oil fields are the preferred storage method because they are already proximate to consumption centers and/or the pipelines needed to transport the gas.
Legal Aspects of Pipeline Construction

• The cost and project time of laying new natural gas pipelines has increased due to Congress’ imposition of federal construction standards.

• Proposed pipeline projects must obtain numerous local, state and federal permits, which address all natural resources.

• Adding new pipe near an existing pipeline requires a significant amount of communication and written approval (digging procedures, violations of ROW, etc.)

Pipeline regulation is handled by:
• The Federal Energy Regulatory Commission (FERC)
  • The U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA)
  • The U.S. Environmental Protection Agency (EPA)
  • The U.S. Occupational Safety and Health Administration (OSHA)
  • The Public Utilities Commission (PUC)
Procedural Aspects of Pipeline Construction

The steps involved in laying a new pipeline include:

- Obtaining permits (Local, state, and federal)
- Surveying and Staking
- Clearing and Grading
- Trenching
- Pipe stringing, bending and welding
- Lowering-in and backfilling
- Hydrostatic Testing
- Final tie-in and cleanup/restoration
Pipeline Installation Workforce

• Construction crews are typically on site for about 6 to 12 weeks.
• A typical crew installs about 1 mile of pipe per day.
• A typical compressor station can be constructed by about 100 workers and five inspectors. Site preparation takes about 16 to 20 weeks; actual construction takes over 6 months.
• The 78-mile Millennium Pipeline was initially built in 1 year (2002-2003); it was later expanded to its current length (260 miles) in 2007-2008.

<table>
<thead>
<tr>
<th>Labor Category</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe fitters and welders</td>
<td>6</td>
</tr>
<tr>
<td>Equipment operators</td>
<td>27</td>
</tr>
<tr>
<td>Truck drivers</td>
<td>29</td>
</tr>
<tr>
<td>Laborers (including welder’s helpers)</td>
<td>18</td>
</tr>
<tr>
<td>Supervisory</td>
<td>6</td>
</tr>
<tr>
<td>Others (inspectors, electricians, ironworkers, etc.)</td>
<td>13</td>
</tr>
</tbody>
</table>

Source: “Natural Gas Pipeline Technology Overview” p.26
Environmental Aspects of Pipeline Construction and Operation

- Although transient and locally concentrated, construction equipment and vehicles produce direct emissions as the pipeline is installed.
- There are analogous emissions associated with the construction of the compressor station and processing plant.
- There are negligible emissions from the compressor stations during regular operation, and close to zero emissions from the pipeline itself.

### Typical Emissions from the Construction of a Pipeline Segment

<table>
<thead>
<tr>
<th>Type of Construction Equipment</th>
<th>Pollutant Emissions (pounds [lb]/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO</td>
</tr>
<tr>
<td>Diesel track-type tractors</td>
<td>233.7</td>
</tr>
<tr>
<td>Diesel wheel-type tractors</td>
<td>396.7</td>
</tr>
<tr>
<td>Fugitive dust from disturbed acreage</td>
<td>51.6</td>
</tr>
<tr>
<td>Heavy-duty diesel vehicles</td>
<td>7,058.0</td>
</tr>
<tr>
<td>Heavy-duty gasoline vehicles</td>
<td>62.6</td>
</tr>
<tr>
<td>Light-duty diesel trucks</td>
<td>540.4</td>
</tr>
<tr>
<td>Light-duty gasoline trucks</td>
<td>33.3</td>
</tr>
<tr>
<td>Light-duty gasoline vehicles</td>
<td>10.1</td>
</tr>
<tr>
<td>Miscellaneous equipment—gasoline</td>
<td>437.9</td>
</tr>
<tr>
<td>Miscellaneous equipment—diesel</td>
<td>NA</td>
</tr>
<tr>
<td>Total</td>
<td>8,824.3</td>
</tr>
</tbody>
</table>

\textsuperscript{a} NA = not applicable. Source: EPA (2000).
Economic Impacts of Natural Gas Transport via Pipeline

• Pipeline networks are often seen as a bottleneck in infrastructure when projecting future production.

• Natural gas producers often drill wells and then cap them until the pipeline infrastructure can be built to carry the gas to market.

• It is therefore generally assumed that there will be a lag of one year between the time a well is drilled and when it is able to produce marketable gas.
Future Pipeline Development in the Marcellus Region

• The region of the Marcellus that lies in Pennsylvania has seen the most expensive pipeline development in 2011, averaging about $300,000 per mile.

• $30 Billion in infrastructure projects needed over the next 5 years to meet projected production; $100 Billion needed over the next 20 years

• 2000 well permits were issued in 2010 in Pennsylvania alone; most of these wells will require new gathering lines to be built to transport the gas from wellhead to market.
Wildlife (#68-70)
3 Areas of Concern

1) Water Withdrawals from Hydraulic Fracturing
   - No controls on the rate, timing and location of withdrawals
   - Stream flow modifications could negatively impact:
     a) **Aquatic Ecosystems**
        • Produces unsuitable H₂O temperature and dissolved O₂ concentrations
        • Impacts more severe when existing pollutants from point sources (e.g. discharge pipes) and non-point sources (e.g. runoff from farms and paved surfaces) become concentrated
     b) **Downstream Riverine and Riparian Resources**
        • Effluent limits are controlled by the stream’s flow rate
        • Natural flow conditions produce dynamic river channel that constantly changes as substrates are scoured, moved downstream, and re-deposited
     c) **Downstream Wetlands**
        • Mere existence depends on presence of water at or near soil’s surface
        • Need inflow/outflow of surface water and/or groundwater to maintain wetland functions
     d) **Aquifer Supplies**
        • Depletion reduces groundwater discharge into streams
        • Natural flow regime shaping the stream channel and maintaining its biological diversity is disrupted
2) Potential transfer of invasive plant species’ seeds and roots to another location on site or to a separate project site as the result of truck, hose, and pipeline activity from hydraulic fracturing
   - Invasive species spread wildly (no native predators/diseases to control population)
   - Outcompeting of native species diminishes biological diversity and alters natural community structure

3) Centralized Flowback Water Surface Impoundments
   - Waterfowl use impoundments during migration or when impoundments are located near a feeding area such as a cornfield
   - Long term exposure to flowback water may be harmful to waterfowl
Summary-Environmental Concerns

• Environmental concerns are relatively minor and trumped by potentially large economic benefits accrued from hydraulic fracturing in the Marcellus Shale
  – **Groundwater Contamination**: Leakage from casing or casing cement is not a problem due to natural barriers and protection factors but contamination at the surface from improper handling and disposal of wastewater is still a problem but one that can be easily managed through regulations
  – **Wastewater Disposal**: TDS buildup from conventional wastewater treatment plants is a problem but alternative treatment and fracking options are available
    • Niagara Falls Wastewater Treatment Plant, injection of wastewater into existing deep wells, propane fracking
  – **Overuse of Water Resources**: not a problem, hydrofracking 100 wells uses 3% of the maximum approved daily consumptive use
  – **Infrastructure Damage**: a problem for poorly built town roads, especially after spring melt, but the number of truck trips can be reduced by:
    • Using multi-well pads, recycling flowback water for fracking operations, and centralizing water impoundment locations

• Marcellus is the least developed major shale basin in the US with great economic potential
  – $30,000/acre
  – NPV for a single well (after 20 yrs of production) is estimated to be between $2.8 and $6.7 million
  – Power density (assuming 30 yrs to recovery) is 1.6 W/m²
Environmental Conservation Laws!
This is the body of law that established the DEC and authorizes its programs.

Regulates the disposal, transport, and treatment of hazardous and toxic wastes in an environmentally sound manner.

Regulates mining, including reclamation of mined lands, extraction of oil and gas, and underground storage of natural gas and liquefied petroleum gas.

Monitor environmental conditions and tests for contaminants.
1963 – New York enacts comprehensive oil and gas law. Law regulates well spacing, wasting oil and gas, flaring gas, and protecting surface and groundwater supplies. Enables state to obtain geologic information and require ownership records.

1988 – DEC issues Draft Generic Environmental Impact Statement (DGEIS) for oil and gas proposing to regulate all oil and gas wells in the state through a single EIS review.

2009 - DEC issues Draft Supplemental Generic Environmental Impact Statement (DSGEIS) on Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs, which proposes changes in the permit requirements for certain types of gas wells.
So What’s the Hold Up?

The Revised Draft SGEIS, Dec. 13, 2010. Gov. Paterson issued an order requiring DEC to perform additional review of the environmental impacts of high-volume hydro fracturing and horizontal drilling. This review was to be completed by June of 2011 and then opened to public comment. The Preliminary Revised Draft SGEIS was issued July 2011 and the Revised Draft SGEIS was issued September 7, 2011. The comment period was extended by Governor Cuomo to January 11, 2011.
What is the DEC Doing?

“The Department (DEC) is assessing the chemical makeup of these additives and will ensure that all necessary safeguards and best practices are followed.”

They say that the “Fluid removed from the well is required by law to be handled, transported and disposed of properly.”

http://www.dec.ny.gov/energy/46288.html
Remember
Money Talks!
Were talking $3,000 to $30,000 initial gross royalties per well per month!
Questions?

Visit the DEC’s webpage:
http://www.dec.ny.gov

Ask Chesapeake Energy at:
http://www.askchesapeake.com

Read all about the science at:
http://geology.com

See References Slide #90
Replacing AES Cayuga
## Fossil Fuel Emission Levels
- Pounds per Billion Btu of Energy Input

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Natural Gas</th>
<th>Oil</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide</td>
<td>117,000</td>
<td>164,000</td>
<td>208,000</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>40</td>
<td>33</td>
<td>208</td>
</tr>
<tr>
<td>Nitrogen Oxides</td>
<td>92</td>
<td>448</td>
<td>457</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>1</td>
<td>1,122</td>
<td>2,591</td>
</tr>
<tr>
<td>Particulates</td>
<td>7</td>
<td>84</td>
<td>2,744</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.000</td>
<td>0.007</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Source: EIA - Natural Gas Issues and Trends 1998

http://www.naturalgas.org/environment/naturalgas.asp
Death and Disease from Power Plants

http://www.catf.us/coal/problems/power_plants/existing/
Economics of Fuel Use

Regulating the operation of plants to create energy in the most cost efficient way

• Typically nuclear, coal and geothermal plants are the base load generators (assisted by any renewables that are online)

• Highly efficient NGCC units are used to meet intermediate loads

• For peak power inefficient gas combustion turbines are employed
Fuel is biggest cost in gas plant

Generation Costs at 5% Discount Rate for Natural Gas in the US

- Fuel Costs 88%
- O&M 4%
- Investment 8%
U.S. Electricity Production Costs (2000-2009)\(^{(1)}\)

\[\text{Cents per kilowatt-hour}\]

\begin{align*}
\text{Petroleum} & \quad 12.37 \\
\text{Gas} & \quad 5.00 \\
\text{Coal} & \quad 2.97 \\
\text{Nuclear} & \quad 2.03
\end{align*}

Shifting Gas Prices and Power Generation

• The dispatch of power plants is done with the purpose of minimizing fuel costs
• In 2002 natural gas combined cycle (NGCC) units ran with an average of 70% capacity
• In 2007 and 2008 NGCC units ran at only 40% capacity

Retrofitting AES Cayuga

• Conversion from coal burning to a natural gas combined cycle unit (NGCC)
• Estimated to cost $350 million
• Would create a 1% increase in electric costs for the first year
• Assumes gas prices remain relatively low
### Replacing AES Cayuga

#### Generation Costs at 5% Discount Rate for Natural Gas in the US

- **Construction Costs**
  - $400-800/kWe (kilowatts electrical) (lower than coal and nuclear) 350 MWe cost $140-280 million
  - Construction expenditures spread over 2-3 yrs
  - US: 90% of construction expenses incurred in the 1st yr

- **Operation and Maintenance Costs**
  - $26/kWe
  - Almost half that of coal ($50/kWe) and nuclear ($63/kWe)

- **Fuel Costs**
  - Largest component of generation costs
  - Between 80-90% of total costs depending on country
  - Gas price: $5/kscf

- **Levelized costs**
  - $37-60/MWh (5% Discount Rate)
  - $40-63/MWh (10% Discount Rate)

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OECD 2005

- Natural gas technologies are sensitive to future fuel prices/price volatility rather than to uncertainties in future demand (investment only 8% of total generation costs while fuel is 88%)

- New gas plant appears better deal than retrofit. Don’t build until gas prices stabilize.
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