Upstream Contribution to Greenhouse Gasses in the Appalachian Basin

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Oil and Gas in the Appalachian Basin

- What is now a mountain range was once a shallow sea
- Filled in with sedimentary rock
- Hydrocarbons deposited over millions of years
  - Marcellus – about 384 million years old
  - Utica – about 450 million years ago

Appalachian geology during the Middle Devonian
Oil and Gas in the Appalachian Basin

- O&G drilling in region since 1859
  - Possibly 1 million+ wells
- 19,220 unconventional wells drilled since 2005 (high volume hydraulic fracturing, mostly horizontal)
  - OH – 2,755 (Marcellus + Utica/PP)
  - PA – 12,202 (Unconventional)
  - WV – 4,263 (Marcellus + Utica/PP)
Natural Gas Liquids

- Natural Gas Liquids (NGLs) are heavier hydrocarbons associated with natural gas deposits
- Wet gas – 10 to 200 barrels NGLs per million cubic feet of gas
- Dry gas – Less than 10 barrels NGLs per million cubic feet of gas
- Wet gas geographically clustered due to geologic conditions

### Natural Gas Liquids

<table>
<thead>
<tr>
<th>Natural Gas Liquid</th>
<th>Chemical Formula</th>
<th>Applications</th>
<th>End Use Products</th>
<th>Primary Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethane</td>
<td>C₂H₆</td>
<td>Ethylene for plastics production; petrochemical feedstock</td>
<td>Plastic bags; plastics; anti-freeze; detergent</td>
<td>Industrial</td>
</tr>
<tr>
<td>Propane</td>
<td>C₃H₈</td>
<td>Residential and commercial heating; cooking fuel; petrochemical feedstock</td>
<td>Home heating, small stoves and barbecues; LPG</td>
<td>Industrial, Residential, Commercial</td>
</tr>
<tr>
<td>Butane</td>
<td>C₄H₁₀</td>
<td>Petrochemical feedstock; blending with propane or gasoline</td>
<td>Synthetic rubber for tires; LPG, lighter fuel</td>
<td>Industrial, Transportation</td>
</tr>
<tr>
<td>Isobutane</td>
<td>C₅H₁₂</td>
<td>Refinery feedstock; petrochemical feedstock</td>
<td>Alkylate for gasoline; aerosols; refrigerant</td>
<td>Industrial</td>
</tr>
<tr>
<td>Pentane</td>
<td>C₆H₁₂</td>
<td>Natural gasoline; blowing agent for polystyrene foam</td>
<td>Gasoline, polystyrene, solvent</td>
<td>Transportation</td>
</tr>
<tr>
<td>Pentanes Plus*</td>
<td>Mix of C₃H₆ and heavier</td>
<td>Blending with vehicle fuel; exported for bitumen production in oil sands</td>
<td>Gasoline, ethanol blends; oil sands production</td>
<td>Transportation</td>
</tr>
</tbody>
</table>

* Pentanes plus is also known as “natural gasoline.” Contains pentane and heavier hydrocarbons.
NGLs in Appalachian Basin

• Brookings Institution: Marcellus / Utica wet gas between 4-9 gallons NGLs per Mcf

• Works out to 95-214 barrels per MMcf

• Ethane can exceed 60% of NGLs

• Very high gas production + NGL content → enormous quantity of available NGLs, especially ethane
NGL Content Too High for Gas Pipelines

• Some NGLs need to be removed from gas streams to meet transmission line requirements
• 950-1200 BTUs per standard cubic foot (scf) target
• Hydrocarbons increase in BTUs per scf with size of molecule

<table>
<thead>
<tr>
<th>Hydrocarbon</th>
<th>BTU/scf</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>1,012</td>
<td>CH₄</td>
</tr>
<tr>
<td>Ethane</td>
<td>1,783</td>
<td>C₂H₆</td>
</tr>
<tr>
<td>Propane</td>
<td>2,557</td>
<td>C₃H₈</td>
</tr>
<tr>
<td>Butane</td>
<td>3,369</td>
<td>C₄H₁₀</td>
</tr>
<tr>
<td>Pentane</td>
<td>4,009</td>
<td>C₅H₁₂</td>
</tr>
<tr>
<td>Hexane</td>
<td>4,756</td>
<td>C₆H₁₄</td>
</tr>
<tr>
<td>Heptane</td>
<td>5,503</td>
<td>C₇H₁₆</td>
</tr>
<tr>
<td>Octane</td>
<td>6,249</td>
<td>C₈H₁₈</td>
</tr>
</tbody>
</table>

Source: EnggCyclopedia
What to do With Ethane Glut? Plastics.

Disposable plastic bag. Image source: www.amazon.com

Ocean plastic. Image source: www.worldatlas.com
Exponential Projection

• Gas plant liquids are NGLs removed from natural gas stream

• NGL production mirrors gas production
  • 2013 – 87,000 barrels per day (bpd)
  • 2017 – 610,000 bpd
  • 2025 – 1.35 million bpd (projected)
  • 2050 – 1.93 million bpd (projected)

• Roughly 50% of NGLs is ethane (950,000 bpd in 2050)

• Context: Shell cracker in Beaver County will consume about 107,000 bpd of ethane

• In 2015, PA produced 3.8 times more natural gas than it consumed
Is There a Demand For More Plastics?

- Increased US supply (Appalachia, Gulf Coast)
- European Union single-use plastic ban
- India single-use plastic ban? (Plan on hold)
- California single-use plastic ban
- Reduced demand in China

Seven year price trend. Source: IHS Markit
Still Planning to Build

• Necessary to develop the gas
• Rumors of up to five crackers in Appalachia (Eastern KY to Western PA)
• Will require additional infrastructure for NGL (cryogenic facility, pipelines)
• Will also have to be accompanied by additional infrastructure for gas (pipelines, compressors, wells)

Future buildout may be 3 times current infrastructure
Upstream Buildout – Well Pads

• Industry projection: 47,600 new unconventional wells
  • 2016 to 2045
  • Just Marcellus
  • Just Pennsylvania

• These wells will require at least
  • 583 billion gallons fresh water
  • 386 million tons of sand
  • 798,000 acres of land
  • 323 million truck trips

Permanent land clearing for projected well pads, gathering lines, access roads, and related infrastructure in PA will total 798,000 acres, about the combined size of Allegheny, Montour, Delaware, and Philadelphia counties.
Midstream Buildout – Pipelines, Compressors, and Processing Plants

- Distribution and gathering lines
  - At least 50’ Right of Way
  - 6.06 acres / linear mile
  - Gathering - about 3.1 miles per pad (calculated with well pads)
  - Gas transmission – 3x current capacity
  - Hazardous liquids – 3x current capacity

- Compressors & processors
  - Require Fuel to operate
  - Leaks, venting, & flaring are routine
  - 3x current capacity to keep up with pipelines

Infrared FLIR video showing emissions from compressor station. Source: Earthworks

Pipeline buildout in the Upper Ohio River Valley. Source: FracTracker
Carbon Costs

• 2015 GHG report lists Natural Gas Systems contributing 204.8 million Mt of CO2e
  • Does not include Aliso Canyon leak
  • About 1.8% of CO2e attributable to plastic (3.7 million Mt CO2e)
    • Ethane about 4.2% of NG
    • About 44% of ethane used as feedstock

Does not include:
• Thousands of truck trips per well
  • 57,000 to 295,000 Mt CO2e attributable to plastic
• New pipeline construction
  • about 1,469 Mt CO2e per mile
  • Average 35,436 new miles per year
  • 937k Mt CO2e to plastics
• Deforestation
  • One time release – 59,461 Mt CO2e for 2015 activities to plastics
  • Lack of carbon sink moving forward (forested areas remove 1.02 Mt CO2e per acre)
Sources

- Middle Devonian map: https://upload.wikimedia.org/wikipedia/commons/3/3b/Eastern_North_American_Paleogeography_Middle_Devonian.png
- 950 – 1,200 BTUs per cubic foot pipeline target: https://www.sciedirect.com/topics/engineering/pipeline-gas-specifications
- Ohio River infrastructure map: http://ft.maps.arcgis.com/apps/webappviewer/index.html?id=1370dd8bd9849e0b363e9384298edeb
- Earthworks FLIR compressor station emissions: https://www.youtube.com/watch?v=sH44JmG410M
- Appalachian buildout analysis and maps: https://www.fractracker.org/2019/07/the-petrochemical-buildout-ohio-river/
- PA Marcellus well projection: https://www.cna.org/cna_files/pdf/Maps1_WellProjections.pdf