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Presentation Overview

- Modern Energy Sources
- Chesapeake Energy Operations
- Keys to Shale Development
- Water / Energy Nexus
- Water Use Efficiency by Shale Play
- Raw Fuel Source Water Use Comparison
  - “Permanent Removal” of Water from Cycle
- Water Use Efficiency of Power Plants
- Water Intensity of Transportation Fuels
- Closing Thoughts
Modern Energy Sources

Source: ALL Consulting, 2010
Chesapeake Energy Operating Areas

- Powder River Basin: Niobrara and Frontier
- DJ Basin: Niobrara and Codell
- Anadarko Basin: Cleveland/Tonkawa, Springer and Mississippian
- Anadarko Basin: Texas Panhandle Granite Wash
- Anadarko Basin: Colony Granite Wash
- Permian Basin: Delaware Basin
- Permian Basin: Midland Basin
- Williston Basin
- Utica Shale
- Marcellus Shale
- Barnett Shale
- Haynesville Shale
- Bossier Shale
- Pearsall Shale
- Eagle Ford Shale
Keys to Shale Development
Keys to Deep Shale Development

1st Key: Horizontal Drilling

- Begins same as vertical well, but turns just above target reservoir zone
- Exposes significantly more reservoir rock to well bore surface versus a traditional vertical well
- Major advantage is fewer wells drilled to access same reservoir volume
Keys to Deep Shale Development

2nd Key: Hydraulic Fracturing

- Process of creating artificial porosity (fractures) in shale formations deep underground.
- Water with <2% special high viscosity additives is injected under high pressure to fracture the rock.
- A “propping agent” (usually sand carried by the water) is pumped into the fractures to keep them from closing when pumping pressure is released.
- Natural gas can then flow freely from the rock pores through production well to the surface.
Water / Energy Nexus
The Water / Energy Nexus

- **“Water is Essential for Energy Resource Development”**
  - Fuel Extraction
  - Fuel Processing
  - Power Generation Cooling

- **“Energy Resources are Needed for Water”**
  - Development (raw water pumping)
  - Processing (treatment)
  - Distribution (potable water pumping)

- **“Balance” or “Nexus” is Critical but Often Overlooked when evaluating Energy Resources**
  - Many discussions on air quality and surface pollution impacts
  - Limited discussion on water availability
  - Improve One → Improve the Other
# Current Chesapeake Water Use by Shale Play

<table>
<thead>
<tr>
<th>Liquid Shales (Gas, Oil, Condensate)</th>
<th>Gas Shales (Dry Gas)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eagle Ford Shale</strong></td>
<td><strong>Niobrara</strong></td>
</tr>
<tr>
<td>125,000 Gallons used for Drilling</td>
<td>300,000 Gallons used for Drilling</td>
</tr>
<tr>
<td>5,000,000 Gallons used for Fracturing</td>
<td>3,000,000 Gallons used for Fracturing</td>
</tr>
<tr>
<td>~ 5.1 Million Gallons Used Per Well</td>
<td>~ 3.3 Million Gallons Used Per Well</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Barnett Shale*</th>
<th>Marcellus Shale*</th>
</tr>
</thead>
<tbody>
<tr>
<td>250,000 Gallons used for Drilling</td>
<td>85,000 Gallons used for Drilling</td>
</tr>
<tr>
<td>4,600,000 Gallons used for Fracturing</td>
<td>5,600,000 Gallons used for Fracturing</td>
</tr>
<tr>
<td>~ 4.8 Million Gallons Used Per Well</td>
<td>5.7 Million Gallons Used Per Well</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Haynesville Shale</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>600,000 Gallons used for Drilling</td>
<td></td>
</tr>
<tr>
<td>5,000,000 Gallons used for Fracturing</td>
<td></td>
</tr>
<tr>
<td>~ 5.6 Million Gallons Used Per Well</td>
<td></td>
</tr>
</tbody>
</table>

*Play contains areas of condensate liquids but primarily dry gas*
# Water Use Efficiency in Major Shale Plays

<table>
<thead>
<tr>
<th>Shale Play</th>
<th>Average Water Use Per Well</th>
<th>CHK Est. Avg. Natural Gas Equivalent Production Over Well Lifetime</th>
<th>Assumed % Energy from Source</th>
<th>Resulting Energy Production Per Well Over Well Lifetime</th>
<th>Water Use Efficiency (in gallons per MMBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haynesville</td>
<td>5.6 million gallons</td>
<td>6.50 billion cubic feet (gas)</td>
<td>~ 100% Gas</td>
<td>6.68 trillion Btu (total)</td>
<td>0.84</td>
</tr>
<tr>
<td>Marcellus</td>
<td>5.6 million gallons</td>
<td>5.75 billion cubic feet (gas)</td>
<td>~ 100% Gas</td>
<td>5.91 trillion Btu (total)</td>
<td>0.95</td>
</tr>
<tr>
<td>Barnett</td>
<td>4.8 million gallons</td>
<td>3.30 billion cubic feet (gas)</td>
<td>~ 100% Gas</td>
<td>3.39 trillion Btu (total)</td>
<td>1.32</td>
</tr>
<tr>
<td>Niobrara</td>
<td>3.3 million gallons</td>
<td>3.35 billion cubic feet equiv (oil and gas)</td>
<td>~ 69% Oil ~ 31% Gas</td>
<td>3.45 trillion Btu (total)</td>
<td>0.96</td>
</tr>
<tr>
<td>Eagle Ford</td>
<td>5.1 million gallons</td>
<td>3.97 billion cubic feet equiv (oil and gas)</td>
<td>~ 63% Oil ~ 37% Gas</td>
<td>4.08 trillion Btu (total)</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Source: ¹Chesapeake Energy 2011, ²Chesapeake Energy Data ³Based on 1,028 Btu per Cubic Foot Gas and 5,800,000 Btu per BBL oil, USDOE 2011, ⁴Does not include processing British Thermal Unit (Btu) Million British Thermal Units (MMBtu)
Calculating Water Efficiency of Liquids and Oil from Shale

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<tr>
<td>Niobrara</td>
<td>3.3 million gallons</td>
<td>3.35 billion cubic feet equiv (oil and gas)</td>
<td>~ 69% Oil</td>
<td>2.38 trillion Btu (oil) 1.07 trillion Btu (gas)</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>~ 31% Gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.45 trillion Btu (total)</td>
<td></td>
</tr>
<tr>
<td>Eagle Ford</td>
<td>5.1 million gallons</td>
<td>3.97 billion cubic feet equiv (oil and gas)</td>
<td>~ 63% Oil</td>
<td>2.57 trillion Btu (oil) 1.51 trillion Btu (gas)</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>~ 37% Gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>4.08 trillion Btu (total)</td>
<td></td>
</tr>
</tbody>
</table>

» Oil and Liquids Refining (based on USDOE 2006)

- Refining requires between 7 gal to 18 gal of water per MMBtu of Energy
- Niobrara and Eagle Ford Oil Water Efficiency = 7.96 to 19.25 gal water per MMBtu
- Only ~ 10% of water needed to produce refined oil is associated with drilling and fracturing

Sources: 1Chesapeake Energy 2011, 2Chesapeake Energy Data 3Based on 1,028 Btu per Cubic Foot Gas and 5,800,000 Btu per BBL oil, USDOE 2011, 4 Does not include processing 5USDOE 2006: Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water British Thermal Unit (Btu) Million British Thermal Units (MMBtu)
# Raw Fuel Source Water Efficiency

<table>
<thead>
<tr>
<th>Energy resource</th>
<th>Range of gallons of water used per MMBtu of energy produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chesapeake deep shale natural gas *</td>
<td>0.84 – 3.32</td>
</tr>
<tr>
<td>Conventional natural gas</td>
<td>1 – 3</td>
</tr>
<tr>
<td>Coal (no slurry transport)</td>
<td>2 – 8</td>
</tr>
<tr>
<td>(with slurry transport)</td>
<td>13 – 32</td>
</tr>
<tr>
<td>Nuclear (processed uranium ready to use in plant)</td>
<td>8 – 14</td>
</tr>
<tr>
<td><strong>Chesapeake deep shale oil</strong> **</td>
<td>7.96 – 19.25</td>
</tr>
<tr>
<td>Conventional oil</td>
<td>8 – 20</td>
</tr>
<tr>
<td>Synfuel - coal gasification</td>
<td>11 – 26</td>
</tr>
<tr>
<td>Oil shale petroleum</td>
<td>22 – 56</td>
</tr>
<tr>
<td>Oil sands petroleum</td>
<td>27 – 68</td>
</tr>
<tr>
<td>Synfuel - Fisher Tropsch (Coal)</td>
<td>41 – 60</td>
</tr>
<tr>
<td>Enhanced oil recovery (EOR)</td>
<td>21 – 2,500</td>
</tr>
<tr>
<td><strong>Biofuels (Irrigated Corn Ethanol, Irrigated Soy Biodiesel)</strong></td>
<td>&gt; 2,500</td>
</tr>
</tbody>
</table>

Source: USDOE 2006 (other than CHK data)

*Includes processing which can add 0 - 2 gallons per MMBtu

**Includes refining which consumes major portion (90%) of water needed (7-18 gal per MMBtu)

Solar and wind not included in table (require virtually no water for processing)

Values in table are location independent (domestically produced fuels are more water efficient than imported fuels)
Fuel Source Water Use Efficiency

Wind and solar notes
- Solar and wind power not included in previous table
  - Require virtually no water for processing
  - Most water efficient
  - Currently not “baseload” worthy
    - Wind: 0.5% of all U.S. energy in 2008
    - Solar: 0.1% of all U.S. energy in 2008
Raw Fuel Source Water Use Efficiency: Geography / Location

**Geography Plays Important Role in Fuel Source Water Efficiency**

- Values in table are location independent
- Energy demands of fuel transport not considered
- If considered:
  - Locally produced fuels would be given higher “value”
  - Imported fuels less water efficient → lower “value”
    » Foreign Oil, Alaskan Oil and Gas, Off-Shore Oil and Gas
Criticism of Oil and Natural Gas Water Use

- Concerns of the so-called “permanent removal” of water from the effective hydrologic cycle.
  - Most water used in shale development either remains in the formation or returns as produced water.
  - The preferred method for disposal of produced water is through permitted Class II SWDs.
  - Argument that this is a different type of “consumption” than the evaporation of water from a power plant and other types of “consumption.”
Natural Gas Combustion: Water Vapor Generation

» Balanced Methane Combustion Reaction:

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]

» Volume of Water Vapor Produced per Million Cubic Feet of Natural Gas:

- 10,675 gallons

» Need to combust 525 MMCF of natural gas to produce an equivalent amount of water (as vapor) used to drill and complete a typical Marcellus Shale well

- Based on current production trends, it takes an average CHK Marcellus Well < 6 months to produce 525 MMCF of Natural Gas

* Not all natural gas that is consumed is combusted. According to 1995 DOE Topical Report, approximately 3.5% of natural gas is used as feedstock for ammonia, methanol, and ethylene production.
Typical Efficiencies of Thermoelectric Power Plants

14% Flue Gas
36% Cooling Water
50% Electricity
100% Fuel

33% Flue Gas
33% Cooling Water
33% Electricity
100% Fuel

15% Flue Gas
35% Cooling Water
50% Electricity
100% Fuel

0% Flue Gas
33% Cooling Water
33% Electricity
100% Fuel

Source: Adapted from Stillwell et al. 2009
Power Generation Water Use Efficiency
Parasitic Effect of Carbon Capture

(Including raw fuel source and carbon capture input)

Source: USDOE 2006 (other than CHK data) and USDOE/NETL 2007
*Average consumption for fuels; Chesapeake data
MWh = megawatt-hour

Deep Shale Natural Gas Combined Cycle *  
Integrated Gasification (from Coal) Combined Cycle  
Coal Steam Turbine  
Nuclear Steam Turbine  
Concentrating Solar
Transportation Fuels and Water Use

- **Conventional Petroleum and Gasoline Dominate U.S. Market**
  - 97% of all fuels
  - Some contain 10% ethanol blend to reduce air emissions

- **Currently Looking at “Unconventional” and “Alternative” Fuels**
  - Non-Conventional Liquid Fossil Fuels (fuels from coal, oil shale, tar sands)
  - Biofuels (ethanol, biodiesel)
  - Compressed Natural Gas
  - Hydrogen (carrier source)

- **Major “Push” to Electric Vehicles**
  - Major focus of research and development
  - Perceived to be “green” (how is electricity generated?)
  - Increase in water use “overlooked”
Water Intensity of Transportation Fuels

Compressed Natural Gas (CNG)
Source: Adapted from King and Webber 2008a;
*Adapted from King and Webber 2008b, combined with data from USDOE 2006
Non-irrigated biofuels not shown on plot above

Gasoline with 10% irrigated ethanol blend: ~ 200 gallons water consumed per 100 miles driven
Closing Thoughts

- **Deep Shale Oil and Natural Gas**
  - Uses water primarily during drilling and stimulation
  - Produces tremendous amount of energy over the lifespan of a well
  - Misconception that drilling and hydraulic fracturing processes use a “large” volume of water, and that this volume of water is “lost” from water cycle

- **Raw Fuel Source Water Use Efficiency**
  - Natural Gas (including Shale Gas), Wind, and Solar are most efficient
  - Drilling and fracturing accounts for ~ 10% of the water needed to produce refined oil
  - Even with hydraulic fracturing water demands, shale oil is equivalent to conventional oil
  - Shale operators continuing to try and reuse produced water where feasible
  - Water Vapor from Natural Gas (and Oil) combustion more than offsets any “loss” from cycle

- **Power Generation and Transportation Fuel Water Use Efficiency**
  - Natural Gas Combined Cycle (NGCC) Plants are among most efficient, even with carbon capture
  - Conventional transportation fuels (gasoline and diesel) are relatively water efficient, but natural gas based fuels are best

- **Location is Important!**
  - Water and energy used to transport people and products
  - When fuel is imported, there are unintended environmental impacts

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Natural Gas Combustion: Water Vapor Generation

- **Balanced Methane Combustion Reaction:** \( CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \)

- **Water Vapor Production Calculation Assumptions:**
  1. Typical Natural Gas Makeup: ~ 95% Methane (remaining ~ 5% as Ethane, Propane, Butane, etc)
  2. Take conservative approach any only use methane to calculate water vapor *
  3. Assume normal temperature and pressure (68°F and 1 atm)
  4. Volume of 1 mole of CH4 at 68°F is 0.0026 mole/cu-ft
  5. Molecular weight of water is 18 lb/lb mole
  6. Liquid water density at 68°F is 8.33 lb/gallon

- **Volume of Water Vapor Produced per Million Cubic Feet of Natural Gas**
  \[
  (1,000,000 \text{ cu-ft of CH}_4) \times (0.95) \times (0.0026 \text{ lb mol CH}_4 / \text{ cu-ft of CH}_4) \times (2 \text{ lb mol H}_2O / 1 \text{ lb mol CH}_4) \times (18 \text{ lb H}_2O / 1 \text{ lb mol H}_2O) \times (1 \text{ gal H}_2O / 8.33 \text{ lb H}_2O) = 10,675 \text{ gallons}
  \]

- **Approx 10,675 gallons of water produced per MMCF of natural gas combusted**

- **This equates to approx 525 MMCF of natural gas needed to combust to produce an equivalent amount of water used in a Marcellus frac job**
  - A typical CHK Marcellus Shale well is projected to produce approx 5,200 MMCF of natural gas over its lifetime. Based on current data, it takes an average CHK Marcellus Well < 6 months to produce 525 MCF of natural Gas

* Not all natural gas that is consumed is combusted. According to 1995 DOE Topical Report, approximately 3.5% of natural gas is used as feedstock for ammonia, methanol, and ethylene production.
Carbon Capture and the Parasitic Effect on Power Generation and Water Use

- Three of the power plant types evaluated emit CO₂
  - Natural Gas Combined Cycle (NGCC)
  - Integrated Gasification (SynGas from Coal) Combined Cycle (IGCC)
  - Coal / Biomass Steam Turbine
- Believed technological solution is the use of carbon capture, (combined with deep geological sequestration)
- Commonly overlooked in the discussion of carbon capture is the parasitic effect the carbon capture technology has on power generation efficiency
- When the efficiency of a power plant is decreased, additional generating capacity must be brought online to maintain the plant’s previous electrical output
- Results in a reduction of the water efficiency of power plants that incorporate carbon capture